ARMY RESEARCH LABORATORY

An Assessment of Camera Position Options and Their Effects on Remote Driver Performance

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Abstract

This report describes a study that compares the effects of three camera positions on remote driving performance of a high mobility multi-purpose wheeled vehicle (HMMWV). The three camera positions assessed had been selected during a previous study based on driver opinion about the adequacy of the view and the ease of performing the remote driving task.

The present study was conducted on an outdoor course that consisted of a straightaway, slalom, serpentine, and parking segment. These segments were configured using traffic cones.

No significant differences were found among the three camera positions in course completion time; however, those traffic cones that defined the slalom and serpentine segments of the course were hit significantly less often in one camera position than in the other two. Further analyses revealed relationships between camera height and course completion time and error. Relationships were also found between time and error and the distance from the front of the vehicle at which the ground to either side of the vehicle's hood was visible.

The report includes equations to assist in identifying camera position options that offer the most efficient and effective distribution of the driving scene among sky, far and near ground, and the teleoperated platform.

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EXECUTIVE SUMMARY

The location and angle of the camera on board a remote vehicle will determine the distribution of the driving scene among sky, far and near ground, and the teleoperated platform. Each of these sectors of the scene contains information needed to perform the driving task, but there has been no research that suggests how changes in the view in any of these sectors might affect remote driving performance.

The present study was conducted by the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) in support of the program manager-unmanned ground vehicles (PM-UGV). In this study, it was hypothesized that the remote driver's ability to view the ground with respect to the teleoperated platform would significantly affect his or her ability to follow paths and avoid obstacles.

This study was preceded by a series of pilot investigations in which drivers rated a multitude of combinations of camera locations and angles based on the adequacy of the view and the perceived ease of performing the driving task. These assessments focused on four sectors of the driving scene, which included the lateral and longitudinal views of the vehicle's hood, vision above the horizontal, and ground view close to the front of the vehicle. The subjects were also given the opportunity to identify and rate other sectors of the scene they considered important to the performance of the driving task. The ten positions that subjects rated highest during these initial screenings all provided some vision in each of the four sectors assessed. Those positions that subjects rated lowest provided significantly less or no view in one or more of these sectors.

A similar methodology was then used to reevaluate each of the ten positions and examine the extent to which the subjects' ratings conformed with a set of assumptions derived from military design standards and other literature about visibility requirements for on-board driving. In this latter analysis, some basic trigonometric functions were applied to identify regions on board the high mobility, multipurpose wheeled vehicle (HMMWV) in which camera positions that satisfied these assumptions could be found. The four positions that subjects rated lowest lay on or beyond the borders of the acceptable envelope defined by these formulae. Further calculations of the visual footprint provided at each of the ten positions assessed revealed large differences in ground visibility immediately forward of the HMMWV's hood and to either side of the vehicle's front fenders. These differences appeared to conform with the subjects' ratings of the adequacy of view provided at these positions and the ease of performing the driving task.

Positions 8 and 9, which were among the three positions that subjects rated highest, provided the greatest area of ground visibility to either side of the HMMWV's front fenders. The third camera position, Position 10, provided greater visibility to the immediate front of the HMMWV's hood.

In the final investigation, it was hypothesized that differences among Positions 8, 9, and 10 in these aspects of the driving scene would affect the remote driver's ability to follow paths and avoid obstacles. It was expected that the improved ground visibility that Position 8 provided to either side of the HMMWV's hood would be reflected in the driver's ability to maintain the vehicle within path boundaries. It was also expected that improved ground visibility to the immediate front of the vehicle's hood at Position 10, would allow the driver to better gauge the location of obstacles with respect to the HMMWV's front bumper.

The outdoor course on which the present study was conducted was composed of segments similar to those that the HMMWV traversed in the earlier pilot investigation. As in the previous assessment, these segments were configured using traffic cones. A segment called "parking" was created to provide additional information pertaining to vision close to the front of the vehicle. This segment was also comprised of traffic cones arranged to form a rectangle with an opening at one end. In this segment, the remote driver's task was to drive the HMMWV forward into the parking area and without hitting any of the traffic cones, stop as close as possible to the cones that formed the rear of the enclosure. Driving performance on the slalom, serpentine, and straightaway was scored based on time to complete and errors (i.e., traffic cones hit). In the parking segment, the measure of accuracy was distance; time to complete was not a factor.

The subjects who participated in this investigation were divided into three groups. Each group was trained to the point at which they achieved an asymptote in remote operation of the HMMWV and completed three runs through the course with the camera mounted in one of the three different positions. The data from these three trials were used to determine if there were any statistically significant differences in driving performance among the three groups. Each of the subjects then performed two runs with the camera mounted at each of the three positions, traversing the course in the opposite direction from that driven during the previous trials. After each run, subjects completed a questionnaire similar to that administered during the earlier subjective assessments.

The analyses of remote driving performance at Positions 8, 9, and 10 indicated that there were no significant differences among these positions in course completion time; however, those

traffic cones that defined the slalom and serpentine segments of the course were hit significantly less often at Position 8 than at Positions 9 or 10 ($p < .001$). There were no significant differences in hits between Positions 9 and 10. No errors were committed in the straightaway segment of the course with the camera mounted at any of the three positions, and no differences were found among camera positions in parking accuracy.

The results of the correlation and forward regression analyses of time to complete and error indicated relationships between each of these measures of performance and camera height. Relationships were also found between time and error and the distance from the front of the vehicle at which the ground to either side of the vehicle's hood was first visible.

As in the previous assessments, the subjects noted the need for vision to either side of the HMMWV's front fenders, stating that differences among the three camera positions in this sector of the scene affected their ability to track the location of the obstacles that defined the path with respect to the vehicle chassis. Some subjects also observed that the view in this sector was not among those to be rated in the subjective questionnaire, where analyses revealed no statistical differences among the three camera positions.

At the conclusion of the study when asked about their preference for one of the three camera positions, eight of the 18 subjects chose Position 8, and nine selected Position 10. Only one subject claimed to prefer Position 9.

AN ASSESSMENT OF CAMERA POSITION OPTIONS AND THEIR EFFECTS ON REMOTE DRIVER PERFORMANCE

INTRODUCTION

The camera is the eye of the remote driver. The focal length of the camera's lens will determine the driver's vertical and horizontal fields of view (FOVs). The location and angle of the camera on board the remote platform will determine the distribution of the driver's vertical FOV among sky, far and near ground, and the teleoperated platform. The position of the camera will also affect the content of the operator's visual field along the horizontal dimension, to include the view of the immediate terrain through which the vehicle is traveling. Each of these sectors of the scene contains information that is used to perform the driving task. However, there has been no research that defines the remote driver's vision needs in these sectors or camera positions that might achieve the most efficient and effective distribution of the scene.

Military design standards for manned systems (U.S. Army, 1989) specify requirements for ground view at far and near distances and visibility above the horizontal, but the extent to which these requirements conform with the vision needs of the remote driver is uncertain. Forward visibility through the lateral visual field is also addressed and the need for vision to the sides of the vehicle is implied, but some of these requirements may not be achievable within the constraints of the single, fixed camera system, and the impact that deficits in these sectors of the scene might have on remote driving performance has not been defined.

The Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland, in support of the program manager-unmanned ground vehicles (PM-UGV), has developed a program of research to identify visual display and control device design characteristics required for teleoperation, particularly as they apply to the quantity and quality of sensory input actually needed by the remote operator to perform a given task effectively.

The current focus of this research is on the task of remote driving and associated vision requirements. The video image transmitted to the remote operator is provided by a single camera, fixed to the chassis of the remote vehicle. Initial investigations attempt to optimize this configuration and derive a baseline suitable for ensuing experimentation and analyses of the costs and benefits of enhancements of this system.

In 1992, Glumm, Kilduff, and Masley reported the results of a study that was designed to select a lens focal length for this configuration that would maximize remote driving performance. The three lens focal lengths assessed in this study were chosen to provide a narrow and a wide horizontal field of view (HFOV) and an HFOV that lay near midpoint between the two extremes. These focal lengths and their corresponding horizontal FOVs were 12 mm (29°), 6 mm (55°), and 3.5 mm (94°). The results indicated that the 6-mm lens offered a more acceptable trade-off among FOV, resolution, and image distortion than did either the 12-mm or the 3.5-mm focal lengths.

The present study attempted to optimize the driver's perspective within the FOV constraints of the 6-mm lens by examining the effects of camera positioning on the distribution of the remote driver's visual field among sky, far and near ground, and the teleoperated platform.

Whereas the human eye has a vertical FOV of approximately 100° (Woodson & Conover, 1964), a 6-mm lens will constrain the remote operator's view along this dimension to an approximate 43°. Some portion of this view should fall above the horizontal to facilitate navigation and detection of potential hazards that might lie ahead at higher elevations. A view of the ground close to the front of the vehicle aids in obstacle recognition and avoidance, and according to Moore & Smith (1966), this view is necessary when starting, parking, or following other traffic--particularly in fog.

As in on-board driving, the operator of a remote vehicle must maintain a sense of the vehicle's position relative to the immediate environment through which it is traveling. A view of some portion of the vehicle's hood, as well as the corners of the front fenders, provides a reference for maneuvering around obstacles and negotiating narrow paths and passages.

The position of the remote camera will also affect the angle at which an object is viewed and potentially the remote driver's ability to detect, identify, and avoid an impending hazard. At lower camera elevations and reduced angles of depression below the horizontal, the operator's perspective of the terrain will change to include his or her ability to discern terrain texture, composition, and surface roughness. Potholes and ditches may lose size, contrast, and definition, and objects may lose the detail needed to spark recognition. During cross-country travel, hazards may be further obscured and their image distorted by ground cover. Losses in resolution will compound these problems, expanding the deficit in knowledge about the terrain to be traversed and obstacles that might jeopardize safe passage.

The quantity and quality of the view or information required in any sector of the scene will vary with task and terrain. Although camera positioning has been among those characteristics of the vision system considered for evaluation (Miller, 1988), there has been no ensuing research to study its effects. In comparisons of remote driving performance using aimed and fixed camera systems, it continues to be a potential source of bias (Spain, 1991). Multiple cameras will expand the operator's horizontal FOV to the front of the vehicle and may improve his or her ability to navigate and detect targets, but the operator's vision needs in other sectors of the scene for the performance of other critical tasks may not be satisfied unless consideration is given to the location and angle at which these cameras are mounted. Although a camera may be panned and tilted toward an area where vision is required, it is important to minimize the need to manipulate camera position and avoid the potential risk of disorientation and motion sickness (Pepper, 1986; Spain, 1991). Whether the camera is fixed or aimed, it is most desirable to select a baseline mounting position that satisfies the remote operator's vision needs for the performance of his or her fundamental tasks.

The present study focused on differences in the content of the driving scene at three remote camera positions and the effects these differences might have on remote driver performance and preference. The three camera positions chosen for this study had achieved the highest overall ratings during earlier subjective assessments (see Appendix A) and were shown to conform to a set of vision criteria derived from military design standards for on-board driving (see Appendix B). These positions, which lay high and toward the rear of the vehicle, also provided greater visibility to the front and sides of the HMMWV's hood than did either of the camera positions originally assessed. In this study, it was expected that differences among the three positions in these sectors of the driving scene would be reflected in differences in the remote driver's ability to follow paths and avoid obstacles.

OBJECTIVE

The primary objective of this investigation was to measure and compare the effects of three camera positions on remote driving performance of a HMMWV and driver opinion as to the adequacy of the view and ease of performing the driving task. It was expected that the improved ground visibility that Position 8 provided to either side of the HMMWV's hood would be reflected in the driver's ability to maintain the vehicle within path boundaries. It was also expected that improved vision close to the immediate front of the vehicle's hood at Position 10 would allow the driver to better gauge the location of obstacles with respect to the HMMWV's front bumper.

METHOD

Subjects

The nine military and nine civilian personnel who participated in this investigation ranged in age from 21 to 35 years with an average age of 29. Of these 18 subjects, 16 were male and two female. All were licensed drivers with 5 to 18 years of experience. All subjects were screened to meet the visual acuity qualifications of the target user group of 20/20 vision in one eye, corrected or uncorrected, and at least 20/100 in the other eye. The military occupational specialties (MOS) of the soldier participants included artilleryman (13A/13B), infantryman (11M), armor crewman (19K), motor transport operator (88M), chemical specialist (54B) and medical laboratory specialist (92B). Most civilian volunteers (77%) were employed as engineers and psychologists.

Apparatus

Research Platform

The research platform was a teleoperated HMMWV, converted for remote operation by Lockheed-Martin Corporation (see Figure 1). The HMMWV was approximately 4.5 m (14.8 feet) long and 2.0 m (6.7 feet) wide. The HMMWV's remote command console incorporated three monitors; the center one was used to display the video image provided by the remote camera. The monitor to its right incorporated touch-sensitive controls which included gear shift, parking brake, and emergency shutdown. The monitor to the left of center displayed vehicle status information such as speed, engine revolutions per minute (rpm), and fuel level.

Video Camera and Mount

The video camera used to provide the subjects their view during remote operation of the HMMWV was a 1/2-inch, charged couple device (CCD) with electronic iris manufactured by Sony (Model SSC-C350). A COSMICAR® 6-mm lens provided a 55° horizontal and 43° vertical FOV. A red filter was attached to the lens to enhance the visibility of the traffic cones that defined the boundaries of the road. A specially designed camera mount and support assembly permitted adjustment of camera angle and location along the vehicle's y (longitudinal) and z (vertical) axes. Camera angle was indexed from 0° to 15° in increments of 5°. The camera mount was attached to a vertical post that would slide along a rail which extended longitudinally down the center of the vehicle. Camera height was adjustable in increments of 7.6 cm (3 inches). The locations and angles of the three camera positions assessed during this study are described in Table 1. The numbers by which these positions are identified are the same as those assigned

during the previous subjective assessment for later comparison of the findings of these studies. Differences between the three camera positions in the visibility provided in key sectors of the driving scene are illustrated in Figures 2 and 3.

Figure 1. The teleoperated HMMWV and remote command station developed by Lockheed-Martin Corporation.

Table 1

Camera Positions 8, 9, and 10: Locations and Angles on Board the HMMWV

Camera position	Y[a] axis (meters)	Z[b] axis (meters)	Θ^c cam (degrees)
8	3.76	1.40	10
9	3.76	1.73	10
10	3.15	1.73	15

[a]Horizontal distance from the front edge of the HMMWV's hood to a point along the longitudinal axis above which the camera body and lens intersect.
[b]Vertical distance from the front edge of the HMMWV's hood to the midpoint of intersection of the camera body and lens.
[c]The angle of depression of the camera below the horizontal.

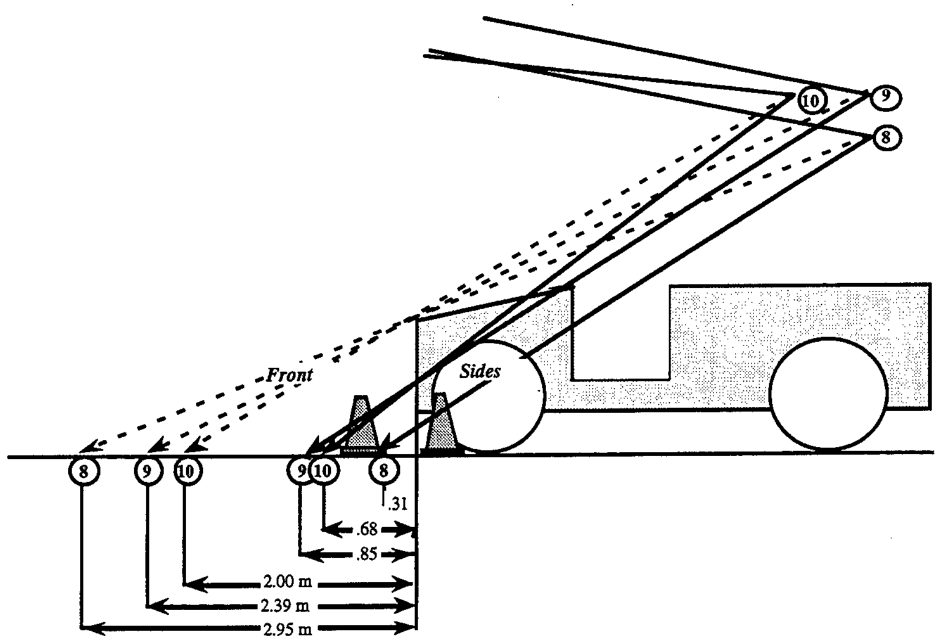

Figure 2. Side view of the HMMWV depicting the operator's line of sight to the ground at the front and sides of the vehicle at Positions 8, 9, and 10.

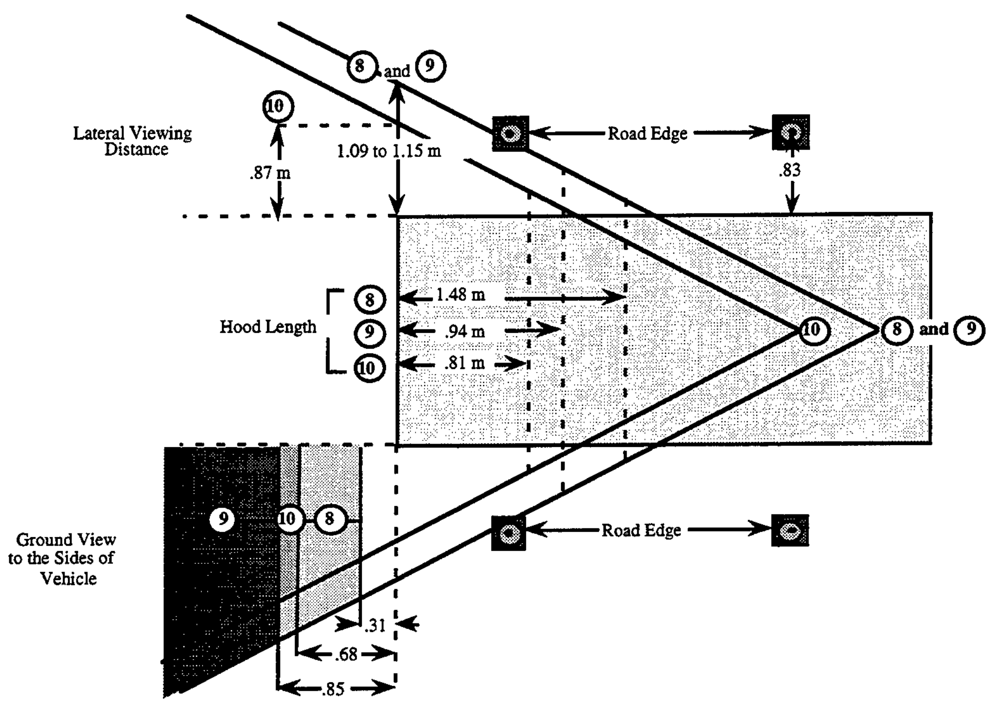

Figure 3. Overhead view of the HMMWV depicting the lateral viewing distance beyond and at the height of the corners of the vehicle's front fenders, the length of hood within the operator's visual field, and ground view to the sides of the HMMWV at Positions 8, 9, and 10.

Transmitter and Receiver

The video image was transmitted by a COHERENT UHF channel video transmitter (Model VT-250) to a S-VHS recorder with receiver (Model BR-3900U) manufactured by JVC.

Monitor

A black-and-white video image was displayed to the subjects on a Sony TRINITRON® monitor (Model PVM-1342Q) with 13-inch screen.

Procedures

Outdoor Test Course

The investigation was conducted on the ATC-ARL robotics test facility's 14-acre outdoor test course at Aberdeen Proving Ground, Maryland. Traffic cones were used to configure four course segments which included a straightaway, serpentine, slalom, and a parking segment (see Figure 4). Cone placement, spacing, and segment length were similar to those of the earlier pilot study.

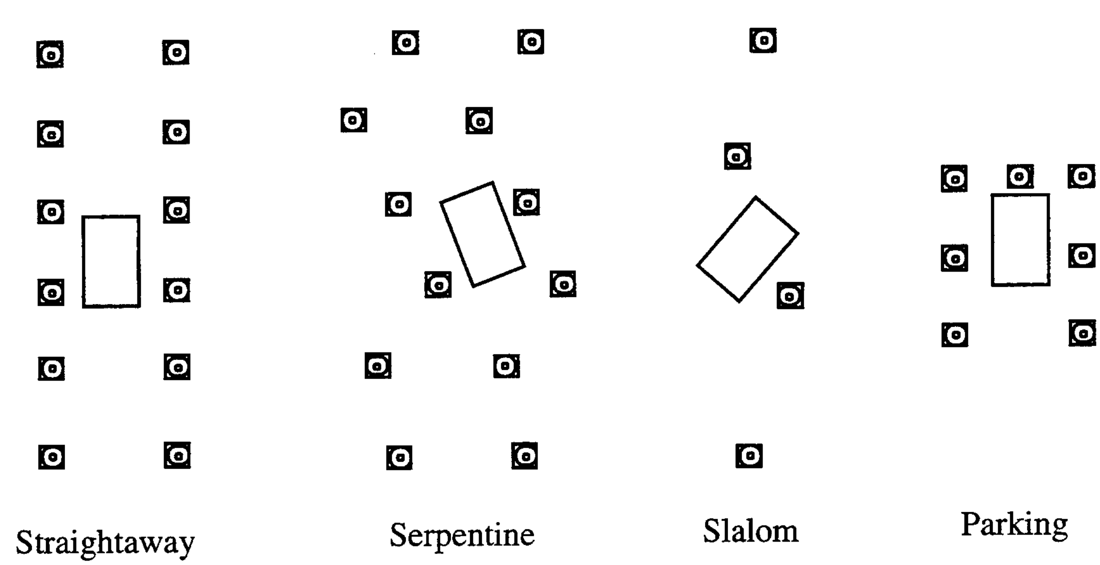

Figure 4. Course segments.

The straightaway (Segment 1) was 98.1 m (322 ft) long and consisted of two rows of traffic cones configured to form a road 3.7 m (12 ft) wide. The traffic cones within each row were also spaced 3.7 m apart. The serpentine segment (Segment 2) was 3.7 m wide and 201.2 m (660 ft) long. Seventeen traffic cones were used to configure the 227.4-m- (746-ft-) long slalom segment (Segment 3). The cones within this segment were spaced between 6.1 m (20 ft) to 12.2 m (40 ft) apart and located at various offsets from an imaginary road centerline. The remote driver was tasked to drive as quickly as possible through each of these segments without hitting any of the traffic cones that defined the path. Optical sensors that marked the beginning and end of each of these segments provided data about time to complete. The measure of accuracy was the number of traffic cones hit. In the slalom segment, failure to maneuver the vehicle between any two traffic cones was also counted as a hit. The number of traffic cones hit was recorded by observers. A fourth course segment called "parking" (Segment 4) provided additional data for assessment of vision close to the front of the vehicle. The parking segment was also comprised of traffic cones arranged to form a rectangle that was 3.7 m (12 ft) wide by 4.3 m (14 ft) long with an opening at one end. In this segment, the teleoperator was asked to drive forward into the parking area and, without hitting any traffic cones, stop as close as possible to those that formed the rear of the enclosure. An ultrasonic sensor measured distance from the traffic cones to the edge of the vehicle's front bumper.

Subject Screening and Pre-Test Questionnaire

An acuity test at far and near distances was administered to each of the 18 volunteers to ensure 20/20 corrected or uncorrected vision in one eye and at least 20/100 in the other eye. This requirement was based on physical qualifications for visual acuity of the target user group. All subjects completed a questionnaire to obtain pertinent demographic and background information (see Appendix C).

Training and Test

Throughout training in remote operation of the HMMWV, 6 of the 18 subjects drove the vehicle with the remote camera mounted at Position 8, another six drove the vehicle with the camera at Position 9, and for the remaining six, the camera was mounted at Position 10. All subjects received instruction and practice in the operation and response of the vehicle controls and system safety mechanisms while performing maneuvers similar to those to be performed during test. After all subjects had completed this preliminary phase of instruction, the course was reconfigured for formal training and test.

During the period that followed, the subjects were trained to an asymptote in remote operation of the HMMWV, and they completed three runs through the course with the camera mounted in one of the three different positions. The data from these three trials were used to determine if there were any statistically significant differences in driving performance among the three groups.

For each subject, this first phase of study was immediately followed by a second in which the subject completed two runs through the course with the camera mounted at each of the two camera positions with which they had no previous experience, as well as at the position on which they were trained. During these trials, the subject drove the vehicle around the course in the opposite direction from that driven during Phase 1. After each run through the course, a questionnaire was administered (see Appendix D). For that camera position at which the run had just been completed, the subjects were asked to rate, on a scale of one to seven, the ease at which they perceived they could maneuver the HMMWV through each of the four course segments and their need for more or less of a view in each of four sectors of the driving scene to perform the task effectively. This questionnaire was similar to that administered during the earlier pilot study and was scored and analyzed in the same manner. At the completion of all runs, the subject was asked to identify his or her preference for one of the three camera positions.

Throughout both phases of test, a motion sickness questionnaire was administered after each run to ensure that symptoms related to motion sickness did not exert an influence on the results of the investigation (see Appendix E).

The design matrix for this experiment is shown in Figure 5. The study was a repeated measures design, with camera position a between-subjects factor and course segments a within-subjects factor. In both phases of the study, the independent variables were camera position and course segment. In Phase 1, the dependent variables were time to complete and error. The measure of error for the straightaway, serpentine, and slalom segments of the course was the number of traffic cones hit. In the last segment of the course (parking), the measure of error was stopping distance from the rear of the enclosure; time to complete was not a factor. During Phase 2 of the study, the dependent variables were subjective ratings of the adequacy of the view and ease of performance.

COURSE SEGMENTS		CAMERA POSITION											
		8	9	10	8	9	10	8	9	10	8	9	10
		Phase 1						Phase 2					
		Time to Complete			Error			Adequacy of View			Ease of Performance		
1	Straightaway												
2	Serpentine												
3	Slalom												
4	Parking	NA											

Figure 5. Design matrix.

RESULTS

Remote Driving Performance (Phase 1)

Time to Complete

The mean number of seconds taken to complete the course segments was subjected to an analysis of variance (ANOVA) with camera position (Positions 8 versus 9 versus 10) and course segment (straightaway versus serpentine versus slalom) as within effects. Allowing for the Greenhouse-Geisser adjustment, only the main effect for course segment was significant, $F(2, 30) = 228.88$, $p < .01$, as shown in Table 2, with a mean number of seconds of 23.72 versus 88.24 versus 81.40 for the straightaway, serpentine, and slalom segments, respectively. This main effect was attributed to differences between the straightaway and the longer, more difficult serpentine and slalom segments of the course. Both the main effect for camera position and the Camera Position x Course Segment interaction failed to reach significance at the .05 level of confidence as shown in Table 3.

Table 2

Mean Time to Complete by Camera Position and Course Segment

Time to complete (seconds)				
	Camera position			
	8	9	10	Mean
Straightaway	27.27	23.77	20.11	23.72
Serpentine	96.27	82.55	85.88	88.24
Slalom	94.66	76.00	73.55	81.40
	72.74	60.77	59.85	

Table 3

Results of Repeated Measures ANOVA of Time to Complete

Source	SS	df	F	*p*
Position	5581.679	2	2.72	NS
Error	15390.67	15		
Segment	135664.456	2	228.88	<.01
Error	8890.97	30		
Position x segment	1525.283	4	1.29	NS
Error	8937.20	30		

Correlation coefficients were computed and forward regression analyses performed to determine if there were any relationships between time to complete and each of five characteristics of the camera positions. These characteristics included the height of the camera (Z axis) and its location along the longitudinal axis (Y axis) of the vehicle, the angle of the camera, the

viewing distance lateral to and at the height of the vehicle's front fenders (x-side), and the distance from the front of the vehicle at which the operator's line of sight intersected the ground to either side of the HMMWV's hood (y-side). The correlation of time to complete and characteristics of the camera positions and segments are shown in Table 4. The results of the regression analyses are shown in Tables 5 and 6. As shown in Table 5, a relationship was found between time to complete and course segment, $F(2, 159) = 334.05$, $p < .001$, which again reflects differences among segments in length and difficulty. A significant but weak relationship was also found between time to complete and camera height (Z axis), $F(2, 159) = 14.46$, $p < .001$. The influence of this Z-axis characteristic was removed because of multi-colinearity with the distance from the front of the vehicle at which the ground to either side of the HMMWV's hood was first visible (y-side). As shown in Table 6, a significant but weak relationship was then indicated between time to complete and the y-side characteristic of camera position, $F(2, 159) = 4.09$, $p < .05$.

Table 4

Correlation of Time to Complete and Characteristics of Camera Positions

Source	Correlation (r)	
	All	Z axis removed
Y axis[a]	0.1100	0.1100
Z axis[b]	- 0.1688 *	-------
Angle[c]	- 0.1100	- 0.1100
x-side[d]	0.0810	0.0810
y-side[e]	- 0.1617	- 0.1617 *
Course segment	0.8113 *	0.8113 *

* $p < .05$
[a]Horizontal distance from front edge of the HMMWV's hood to a point along the longitudinal axis of the vehicle above which the camera body and lens intersect.
[b]Vertical distance from the front edge of the HMMWV's hood to the midpoint of intersection of the camera body and lens.
[c]Angle of depression of the camera below the horizontal.
[d]Viewing distance lateral to and at the height of the corners of the HMMWV's front fenders.
[e]Distance from the front of the vehicle at which the ground to either side of the HMMWV's hood is first visible.

Table 5

The Results of Regression Analyses of Time to Complete
(all characteristics included)

	df	Sum of squares	Mean square	F	p
Regression	2	118876.19	59438.09	174.25	< .001
Error	159	54235.18	341.10		
Total	161	173111.38			

Variable	Parameter estimate	Standard error	Type II sum of squares	F	p
INTERCEP	57.42	15.59	4628.18	13.57	< .001
Z axis	- 35.46	9.32	4931.16	14.46	< .001
Segment	32.48	1.77	113945.03	334.05	< .001

Table 6

The Results of Regression Analyses of Time to Complete
(Z axis characteristic removed)

	df	Sum of squares	Mean square	F	p
Regression	2	425.31	212.65	66.50	< .001
Error	159	508.43	3.19		
Total	161	933.75			

Variable	Parameter estimate	Standard error	Type II sum of squares	F	p
INTERCEP	- 3.33	0.56	111.23	34.79	< .001
y-side	1.41	0.70	13.08	4.09	< .05
Segment	1.95	0.17	412.23	128.92	< .001

Error

Chi-square tests were performed on frequency data shown in Table 7 to examine the mean number of traffic cones hit with camera position and course segment as within-subject effects. The analysis revealed a significant main effect for camera position, $x^2_2 = 11.68$, $p < .001$, with a mean number of hits of 54, 79, and 96 at camera Positions 8, 9, and 10, respectively. No statistically significant differences were found in hits between Positions 9 and 10. The main effect was attributed to the greater area of ground visibility (3.48 m) that Position 8 provided lateral to and forward of the vehicle's front fenders by comparison to Position 9 (2.36 m) and Position 10 (1.50 m). The analysis also revealed a significant main effect for course segment, $x^2_2 = 348.5$, $p < .001$, with a mean number of hits of 0, 209, and 20 for the straightaway, serpentine, and slalom segments, respectively. This main effect was attributed to the differences between segments in length and difficulty. The Camera Position x Course Segment interaction failed to reach significance at the .05 level.

Table 7

Frequency of Errors by Camera Position and Course Segment

Camera position	Course segment			
	Straightaway	Serpentine	Slalom	Total
8	0	52	2	54
9	0	73	6	79
10	0	84	12	96
Total	0	209	20	229

Correlation coefficients were computed and forward regression analyses performed on the natural log of the number of hits to determine if there were any relationships between the number of hits and each of the five characteristics of the camera positions. The correlations of error and characteristics of camera position and segment are shown in Table 8. The results of the regression analyses are shown in Tables 9 and 10. As shown in Table 9, a relationship was found between the number of hits and course segment, $F(2, 159) = 129.43$, $p < .001$, which again reflects the differences among segments in length and difficulty. A significant but weak relationship was also found between the number of hits and camera height (Z axis), $F(2, 159) = 4.75$, $p < .05$. The influence of this Z-axis characteristic was removed because of multi-colinearity with the distance from the front of the vehicle at which the ground to either side of the HMMWV's hood was first

visible (y-side). As shown in Table 10, a significant but weak relationship was then indicated between number of hits and the y-side characteristic of camera position, $F(2, 159) = 4.98$, $p < .05$.

Table 8

Correlation of Errors and Characteristics of Camera Positions

Source	Correlation (r) All	Correlation (r) Z axis removed
Y axis[a]	- 0.1018	- 0.1018
Z axis[b]	0.1273 *	-------
Angle[c]	0.1018	0.1018
x-side[d]	- 0.0817	- 0.0817
y-side[e]	0.1184	0.1184 *
Course segment	0.6644 *	0.6644 *

*$p < .05$

[a] Horizontal distance from front edge of the HMMWV's hood to a point along the longitudinal axis of the vehicle above which the camera body and lens intersect.

[b] Vertical distance from the front edge of the HMMWV's hood to the midpoint of intersection of the camera body and lens.

[c] Angle of depression of the camera below the horizontal.

[d] Viewing distance lateral to and at the height of the corners of the HMMWV's front fenders.

[e] Distance from the front of the vehicle at which the ground to either side of the HMMWV's hood is first visible.

Table 9

The Results of Regression Analyses of Errors
(all characteristics included)

	df	Sum of squares	Mean square	F	*p*	r2
Regression	2	427.35	213.67	67.09	< .001	.46
Error	159	506.39	3.18			
Total	161	933.75				

Variable	Parameter estimate	Standard error	Type II sum of squares	F	*p*
INTERCEP	- 5.65	1.50	44.90	14.10	< .001
Z axis	1.96	0.90	15.12	4.75	< .05
Segment	1.95	0.17	412.23	129.43	< .001

Table 10

The Results of Regression Analyses of Error
(Z-axis characteristic removed)

	df	Sum of squares	Mean square	F	*p*	r2
Regression	2	353.89	176.94	44.91	< .001	.46
Error	105	413.73	3.94			
Total	107	767.62				

Variable	Parameter estimate	Standard error	Type II sum of squares	F	*p*
INTERCEP	9.64	1.13	285.28	72.40	< .001
y-side	2.12	0.95	19.63	4.98	< .05
Segment	- 3.51	0.38	334.25	84.83	< .001

Distance

The mean parking distance (see Table 11) was subjected to an ANOVA with camera position as a within effect. Allowing for the Greenhouse-Geisser adjustment, the main effect for camera position failed to reach significance at the .05 level of confidence, with an overall mean parking difference of 34.09 cm.

Table 11

Mean Parking Distance by Camera Position
(distance in centimeters)

Camera position	Mean	Standard deviation
8	38.02	33.07
9	33.33	30.90
10	30.91	24.44

Subjective Assessment (Phase 2)

A frequency table analysis (log linear model) was performed on the subjective data obtained during Phase 2 which was derived from the subjects' responses to the questionnaire provided in Appendix D. For all camera positions, in the subjects' ratings of both adequacy of the view and ease of performance, the number of responses at either extreme on the seven-point rating scale was often zero. It was therefore necessary to collapse these ratings to either side of the mid-point score to meet the conditions for use of the chi-square statistic which requires that no expected frequency be equal to zero, or that no more than 20% of the expected frequencies be less than five (Dixon & Massey, 1983). Thus, in the analysis of the subjects' ratings of ease of performance of each of the four course segments, all levels of perceived difficulty or ease (i.e., extremely, moderately, and slightly) were included in the count of responses that lay to either side of the mid-point or "neutral" score. Thus, three response categories were created, reflecting a count of the subjects' opinions that maneuvering the HMMWV on a given course segment was "difficult," neither difficult nor easy ("neutral"), or "easy," given the perspective offered of the driving scene at a given camera position (see Appendix F, Table F-1). Chi-square analyses were then performed to determine if significant differences existed among the three camera positions in the subjects' ratings in these three response categories.

The subjects' ratings of the adequacy of the view provided by each of the three camera positions in each of the four sectors of the driving scene for negotiating each of the four segments of the course were handled in a similar fashion. For this subjective measure, the three categories that were created reflected a count of the drivers' perceptions as to the need for "more" of a view, that the quantity of view provided was just right ("neutral"), or that "less" of a view was needed. As in the analysis of the subjects' ratings of ease of performance, all levels of perceived need (i.e., extremely, moderately, and slightly) were included in the count of responses in the "more" and "less" categories which lay to either side of the "neutral" or midpoint response (see Table F-2). The significance of differences among the three camera positions in the subjects' ratings in these three response categories was determined by chi-square analyses.

The results of the chi-square analyses performed on the subjects' ratings of the ease of performance (see Table 12) and adequacy of the view (see Table 13) indicated that there were no statistically significant differences among the three camera positions assessed. Significant main effects, however, were found among course segments in the subjects' ratings of ease of performance, $x^2 = 28.56$, $p < .01$, and among course segments, $x^2 = 29.33$, $p < .01$, and sectors of the driving scene $x^2 = 206.51$, $p < .01$, in ratings of the adequacy of the view. These main effects are attributed to differences between the straightaway and the more difficult slalom and serpentine

segments of the course and the visibility perceived to be needed to perform these different driving maneuvers. Appendix F provides frequency tables (F-3 through F-5) that show where these differences lie.

Table 12

Chi-Square Analysis of Subjective Ratings of Ease of Performance

Source	Chi-square	df	*p*
Position	5.01	4	NS
Segment	28.56	6	<.01

Table 13

Chi-Square Analysis of Subjective Ratings of Adequacy of the View

Source	Chi-square	df	*p*
Position	2.67	4	NS
Segment	29.33	6	<.01
Vision sector	206.51	6	<.01
Position x vision sector	8.32	12	NS

In the analyses of the subjects' ratings of ease of performance, no differences were found between the straightaway and parking segments of the course or between the serpentine and the slalom (see Table F-3), but subjects appeared to perceive these latter two segments to be more difficult to complete than the former ($p < .05$).

For the performance of those tasks addressed in this study (see Table F-4), most subjects were of the opinion that less of a view was needed above the horizon and of the HMMWV's hood, and more of a view needed of the ground close to the front of the vehicle and the edges of the HMMWV's front fenders ($p < .01$). No differences were found between the subjects' ratings

in those sectors of the driving scene where subjects perceived the need for less view, as no differences were found between ratings in sectors where they required more. Generally, the subjects perceived the need for more view to successfully complete all but the straightaway segment of the course (see Table F-5). Differences in the subjects' ratings of the adequacy of the view between the straightaway and each of the other three segments of the course were found to be significant ($p < .05$). No differences were found between the serpentine and slalom segments of the course or between the serpentine and parking segments, but differences between the parking and slalom segments were indicated to be significant ($p < .05$).

At the conclusion of the study, when asked about their preference for one of the three camera positions, 8 of the 18 subjects chose Position 8, and nine selected Position 10. Only one subject claimed to prefer Position 9. Those subjects who preferred Position 10 noted that it provided a more desirable perspective of the HMMWV's hood and the ground close to the front of the vehicle. Those who opted for Position 8 cited the improvement in vision to either side of the vehicle's front fenders. Eight of the 10 subjects who specified other sectors of the driving scene in which vision was required noted the need for vision in this latter area, an area which they observed was not among those to be rated in the subjective questionnaire.

DISCUSSION

The results of this study appear to support the hypothesis that differences in ground visibility to either side of the vehicle's hood will affect the driver's ability to sustain a view of path boundaries and influence the frequency at which the vehicle is driven beyond these boundaries. Vision close to the immediate front of the vehicle, however, did not have the expected impact on the driver's ability to gauge the position of obstacles in relation to the vehicle's front bumper.

Of those characteristics of the three camera positions assessed, the analysis indicated a significant relationship between driving performance and camera height. A significant relationship was also indicated between driving performance and the distance from the front of the vehicle at which the ground to either side of the vehicle's hood was visible. The results of the correlation analyses indicate that as camera height or the distance at which the ground was visible decreased, time to complete increased and errors decreased.

At its lower elevation, ground view directly to the front of the vehicle at Position 8 was more obscured by the hood of the HMMWV than it was at Positions 9 or 10, but vision close to either side of the hood's obstruction was noticeably improved (see Figure 6). One subject

remarked that operating the HMMWV with the camera at Position 8 was "like driving from the back seat of a station wagon," but the subjects also observed that their view of the ground and obstacles to either side of the hood was better at Position 8 than at Positions 9 or 10. At Positions 9 and 10, operators lost their view of the traffic cones that defined the path sooner than they did at Position 8. At Position 8, some portion of the traffic cones to the immediate left and right of the HMMWV's front fenders was captured within the remote driver's visual field. This, the subjects said, helped them to gauge the position of these obstacles in relation to the vehicle's rear wheels.

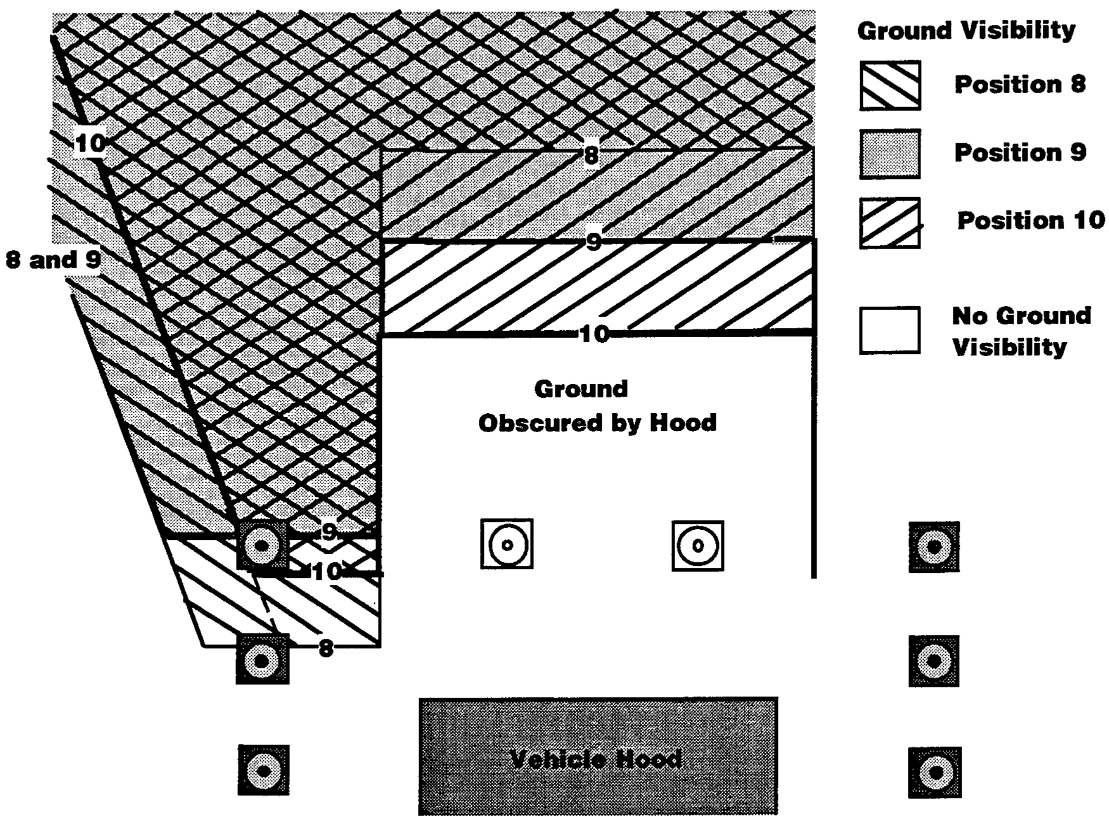

Figure 6. Ground visibility close to the front and to either side of the hood's obstruction at camera Positions 8, 9, and 10 (overhead view).

At Positions 9 and 10, operators may have had greater difficulty in ascertaining the location of the HMMWV with respect to the immediate environment through which the vehicle was traveling. At these positions, operators may have been forced to rely more on their memory of the future path to gauge the vehicle's position with respect to the present. During their runs through the course, operators were heard to periodically express their confidence that the obstacles to one or the other side of the vehicle's front wheels had been successfully cleared, but

this was often followed by some apprehension that the same obstacles were "nailed" by the wheels at the rear. The subjects at times added that vision was better close to the front of the HMMWV at Position 10 but not to the sides.

In hypothesizing why drivers move fast in fog when vision in front of the vehicle is obscured, Moore & Smith (1966) mention experiments in which drivers accurately steered a vehicle at 40 mph through curves even though their direct forward view had been completely blocked. They suggest that in the absence of obstacles, close vision to the front of the vehicle may have little effect on steering. There is also some evidence that the flow of information at the periphery of the driving scene is important to driving performance (Lee, 1980), specifically speed and distance estimation (Osaka, 1988).

It is likely that the similarity in operator performance in the parking segment may not have necessarily reflected any lack of difference among these camera positions in ground view to the front of the vehicle but rather the drivers' ability to judge the location of those traffic cones forward of the HMMWV based on their view of those that formed the corners of the rectangular enclosure (see Figure 6). The split in the subjects' preference between camera Positions 8 and 10, however, along with the qualifications the subjects attached to these preferences, may suggest that the subjects perceived vision close to the front of the vehicle to be as important as that to the sides.

The solution to the equations contained in Appendix B demonstrates that the region on board the HMMWV within which a camera may be mounted will be reduced, particularly at smaller angles of depression, as more stringent requirements for ground visibility close to the front and to either side of the HMMWV's hood are imposed. As shown in Appendix B, for the camera and lens assembly used in this analysis, ground visibility to either side of the HMMWV's hood cannot be achieved at or within 1.0 m from the front of the vehicle at camera angles of 0° horizontal. If a more stringent requirement of ≤ 0.5 m were to be imposed, the area on board the HMMWV within which a camera may be mounted that meets this criterion is further reduced, particularly at depression angles of 10°. Of the 10 camera positions evaluated during the earlier subjective assessment, only camera Positions 7 and 8 lie within the borders of the recomputed sectors for camera angles of 15° and 10°, respectively. A computer program developed to identify camera positions that would satisfy a given set of visual constraints was used to identify a camera location and angle that optimized ground visibility to either side of the HMMWV's hood while still meeting a set of assumptions pertaining to the operator's vision needs in other sectors of the driving scene. The position that was identified lies 1.34 m above and 3.55 m to the

rear of the front edge of the vehicle or 0.04 m below and 0.21 m forward of camera Position 8. Its angle of depression is 13°. At this position, forward vision intersects the ground 2.91 m to the immediate front of the vehicle and 0.0 m to either side of the hood's obstruction.

CONCLUSIONS AND RECOMMENDATIONS

Generally, for any remote ground system, the findings of this investigation show that relatively small changes in the location and angle of the camera on board the remote vehicle will affect changes in sectors of the driving scene that could significantly impact remote driving performance. The study supports the belief that some portion of the front of the vehicle, including the corners of its front fenders, should be within the remote driver's visual field. The results further indicate that ground visibility to sides of the vehicle's hood is needed to enable the driver to estimate the position of the vehicle with respect to the immediate environment through which it is traveling. This implies that displays that provide an artificial reference of vehicle position may be of limited utility. Loss of vision adjacent to the vehicle's fenders may have minimal impact on driving performance on straightaways that are free of hazards, but can significantly degrade the driver's ability to maintain the vehicle within the boundaries of a winding path and avoid obstacles. The likelihood and severity of these degradations in performance, however, will also depend upon the length of the vehicle, its width and turning radius, along with the width and turning radius of the path.

Multiple cameras will expand the remote operator's horizontal FOV beyond the front of the vehicle and may improve his or her ability to navigate and detect targets, but the operator's vision needs in other sectors of the driving scene for the performance of other critical tasks may not be satisfied unless consideration is given to the location and angle at which these cameras are mounted. An analysis to select camera positions that best meet the visual needs of the remote operator may reveal a greater number of designer options to include mounting opportunities for employing rearview mirrors that would supplement the driver's vision to the sides of the vehicle as well as allow the operator to maneuver the vehicle in reverse.

For the performance of the remote driving task, multiple cameras and aimed camera assemblies could be an expensive solution to a problem that may be remedied by a simpler fix. Research to quantify the benefits of these assemblies, by comparison with the single, fixed camera configuration, must attempt to ensure that the results of these efforts are not biased by the effects of camera positioning, or oversight as to the potential that some forethought in placement may afford.

The equations contained in Appendix B, along with a computer program developed to identify camera locations and angles that maximize operator vision in select sectors of the scene, may help to identify camera positioning options that offer the most efficient and effective distribution of the scene among sky, far and near ground, and the teleoperated platform. Use of either the equations or the computer program, however, requires that assumptions be made as to those sectors of the scene important to the performance of the task and the quantity of vision needed in each of these sectors to perform the task effectively.

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APPENDIX A

SUBJECTIVE ASSESSMENT AND ANALYSIS OF RATINGS OF CAMERA POSITIONS 1 THROUGH 10

SUBJECTIVE ASSESSMENT AND ANALYSIS OF RATINGS OF CAMERA POSITIONS 1 THROUGH 10

Objective

The purpose of this pilot study was to select three camera positions for an ensuing study that scored best in subject opinion as to the adequacy of the view and ease of performing the remote driving task.

Method

In this assessment, 20 subjects were shown a video filmed from a camera mounted on a HMMWV. The video was divided into ten parts, each recorded with the camera mounted at a different angle and location on the vehicle. During each part of the film, the HMMWV was driven through each of five course segments that were constructed on the slopes of the Churchville automotive test course. The segments were configured using traffic cones and consisted of an uphill and downhill slalom, an uphill and downhill straightaway, and a serpentine road. The subjects were instructed that the remote driver's task was to maneuver the vehicle as quickly as possible through each of these segments without hitting any of the traffic cones. For each course segment, the subjects were asked to rate each of the ten camera positions on a scale of one to seven, based on the ease with which they perceived they could perform the remote driving task (ease of performance) and their need for more or less of a view in each of the four sectors of the driving scene to perform the task effectively (adequacy of the view). The four sectors of the driving scene included the lateral and longitudinal views of the vehicle's hood and fenders, vision above the horizon, and ground view close to the front of the vehicle. The subjects were also given the opportunity to identify and rate other sectors of the scene that they believed to be important to the task. The questionnaire used in this assessment is provided in Appendix D.

Data Analysis

For each of the 10 camera positions, the number of responses at either extreme on the seven-point rating scale for both subjective measures was often zero. It was therefore necessary to collapse these ratings to either side of the mid-point score to meet the conditions for use of the chi-square statistic that requires that no expected frequency be equal to zero or that no more than 20% of the expected frequencies be less than five (Dixon & Massey, 1983). The subjects' responses were also collapsed over all course segments and sectors of the driving scene. Thus, three response categories were created for each subjective measure. For the adequacy of the

view, these three categories related to the drivers' perception as to the need for "more," "less," or that the quantity of view provided was just right ("neutral"). All levels of perceived need (i.e., extremely, moderately, and slightly) were included in the count of responses in the "more" and "less" categories which lay to either side of the "neutral" or midpoint response. The subjects' scores for ease of performance reflected their opinion that the driving task was "difficult," "easy," or neither difficult nor easy ("neutral"), given the perspective offered of the driving scene. As in the measure of the adequacy of the view, all levels of perceived difficulty or ease were included in the count of responses in each of the first two categories which lay to either side of the "neutral" score.

A tabulation of the subject's ratings of each of the ten camera positions on each subjective measure is provided in Table A-1. These data were subjected to chi-square analyses to determine if significant differences existed between camera positions across each of the three rating categories within each measure.

The results of these analyses are provided in Table A-2. A shaded sector in Table A-2 indicates that the camera position that heads the column scored significantly better than the position at the far left that leads the row in at least one of the three response categories. A darker shaded sector indicates that the camera position that heads the column scored better in at least two of the three categories; a lighter shaded area indicates that a better score was achieved in one of these categories.

Results

Ease of Performance

There were no significant differences among Positions 1 through 5 in the subjects' ratings of ease of performance, as there were no differences among Positions 6 through 10. However, driving with the camera mounted at Positions 1 and 2 was clearly perceived to be more difficult than driving with the camera mounted at the latter six positions ($p < .05$). No significant differences were found between Positions 3 and 4 and Positions 6, 7, or 8. There were also no differences between Positions 5 and Position 7. Only Positions 9 and 10 surpassed all Positions 1 through 5 on ratings of ease of performance ($p < .05$). Positions 9 and 10 were therefore considered the more likely candidates for assessment in the ensuing study.

Table A-1

Subjective Ratings of Camera Positions 1 through 10

CAMERA POSITION	EASE OF PERFORMANCE			
	DIFFICULT	NEUTRAL (Neither Easy or Difficult)	EASY	TOTAL
1	39	8	53	100
2	39	5	56	100
3	27	7	66	100
4	28	7	65	100
5	36	8	56	100
6	14	9	77	100
7	21	10	69	100
8	16	10	74	100
9	12	8	80	100
10	13	9	78	100
TOTAL	245	81	674	1000
CAMERA POSITION	ADEQUACY OF VIEW			
	MORE	NEUTRAL (Just Right)	LESS	TOTAL
1	142	214	44	400
2	118	191	91	400
3	130	203	67	400
4	113	244	43	400
5	137	184	79	400
6	87	224	89	400
7	77	239	84	400
8	90	264	46	400
9	63	240	97	400
10	106	250	44	400
TOTAL	1063	2253	684	4000

Table A-2

Results of Chi-Square Analyses of Subjective Ratings of Adequacy of View and Ease of Performance at Positions 1 Through 10

EASE OF PERFORMANCE										
CAMERA POSITION										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1		NS	NS	NS	NS	16.28	7.72	13.31	19.77	17.82
2	NS		NS	NS	NS	16.25	8.41	13.77	19.22	17.75
3	NS	NS		NS	NS	NS	NS	NS	7.17	6.15
4	NS	NS	NS		NS	NS	NS	NS	8.01	6.91
5	NS	NS	NS	NS		13.05	NS	10.40	16.23	14.46
6	16.28	16.25	NS	NS	13.05		NS	10.40	16.23	14.46
7	7.72	8.41	NS	NS	NS	NS		NS	NS	NS
8	13.31	13.77	NS	NS	10.40	NS	NS		NS	NS
9	19.77	19.22	7.17	8.01	16.23	NS	NS	NS		NS
10	17.82	17.75	6.15	6.91	14.46	NS	NS	NS	NS	
ADEQUACY OF VIEW										
CAMERA POSITION										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1		19.88	NS	NS	12.31	28.66	33.17	16.92	51.85	8.01
2	19.88		NS	23.75	NS	7.33	14.25	30.26	22.47	24.89
3	NS	NS		10.18	NS	12.65	18.41	19.14	31.83	12.08
4	NS	23.75	10.18		21.33	20.26	20.10 [a]	NS	35.06 [b]	NS
5	12.31	NS	NS	21.33		15.67	24.12	32.72	36.61	23.95
6	28.66	7.33	12.65	20.26	15.67		NS	17.02	NS	18.52
7	33.17	14.25	18.41	20.10 [a]	24.12	NS		13.36	NS	17.34 [c]
8	16.92	30.26	19.14	NS	32.72	17.02	13.36		24.09 [e]	NS
9	51.85	22.47	31.83	35.06 [b]	36.61	NS	NS	24.09 [e]		31.06 [d]
10	8.01	24.89	12.08	NS	23.95	18.52	17.34	NS	31.06 [d]	

Scored significantly better in *one* category than camera position in far left column. (light shading)

Scored significantly better in *two or more* categories than camera position in the far left column. (dark shading)

[a]Position 4 scored fewer in "less" category; Position 7 scored fewer in "more."

[b]Position 4 scored fewer in "less" category; Position 9 scored fewer in "more."

[c]Position 10 scored fewer in "less" category; Position 7 scored fewer in "more."

[d]Position 10 scored fewer in "less" category; Position 9 scored fewer in "more."

[e]Position 8 scored fewer in "less" category; Position 9 scored fewer in "more."

Adequacy of the View

The subjects' dissatisfaction with Positions 1, 2, 3, and 5 was more evident in their ratings of the adequacy of the view. The analysis revealed that subjects perceived the view provided at Positions 6 through 10 to be adequate more often than the view provided at Positions 1, 2, 3, and 5 ($p < .05$). The analysis indicated that subjects required less of a view significantly less often at Position 4 than they did at Positions 6, 7, and 9 ($p < .01$). However, it must also be noted that more of a view was perceived to be needed more often at Position 4 than at Positions 7 and 9 ($p < .01$). These findings suggest a shift in the subjects' perception of need from "less" to "more" of a view at Position 4 rather than an increase in the subjects' perception of adequacy. The analysis did not reveal a difference in the subjects' ratings of the adequacy of the view between Position 4 and Positions 8 or 10. There were no significant differences in the subjects' ratings of the adequacy of the view among Positions 6, 7, and 9, as there were no differences between Positions 8 and 10. However, the analyses indicated that the subjects were more satisfied with the view provided at Position 8 than they were with that provided at Positions 6 or 7. At Positions 6 and 7 the subjects demanded less of a view significantly more often than they did at Position 8 ($p < .01$) with no significant shift in the subjects' perceptions of the need for "more" at this latter camera position. Position 8 appeared to offer greater potential than Positions 4, 6, or 7 in satisfying the remote operator's vision needs and therefore was selected with Positions 9 and 10 for the ensuing study.

Visibility Calculations for Positions 1 Through 10

In an attempt to gain some insight about differences among Positions 1 through 10 that might have influenced the subjects' ratings, the visibility provided at these positions (see Figure A-1 and Table A-3) was calculated using the equations contained in Appendix B.

Table A-3 indicates that Positions 2 and 3 did not meet the requirement for ground visibility to the front of the vehicle. Positions 1 and 5 did not provide ground visibility lateral to the sides of the vehicle's hood. The area of ground visibility provided at Positions 7 through 10 was significantly greater than that provided at Positions 4 and 6. In this latter sector of the scene, Positions 8 and 9 provided the greatest visibility. The driver's line of sight intersected the ground closer to the front of the vehicle at Position 10 than it did at Position 7, whereas the line of sight intersect to the ground to either side of the hood's obstruction was closer to the front of the vehicle at Position 7 than it was at Position 10.

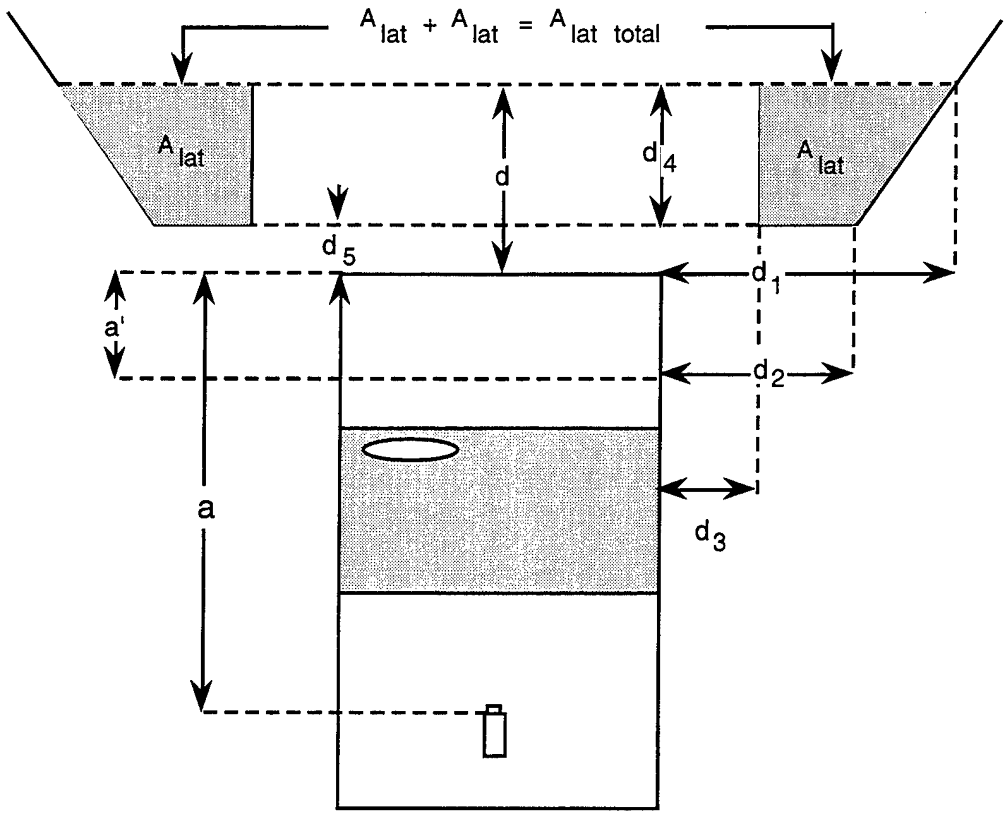

Figure A-1. Defining the lateral vision footprint A_{lat}.

a = camera location along the y axis (longitudinal) as measured from the front edge of the vehicle's hood
a' = the length of hood captured within the vertical field of view (VFOV) of the camera
A_{lat} = the area of ground viewed to each side of the vehicle forward of the front bumper up to the line where forward vision intersects the ground to the immediate front of the vehicle
d = the distance from the front of the vehicle at which the ground first comes into view
d_1 = the distance from the side of the vehicle at ground level to the far lateral, forward longitudinal corner of the lateral vision footprint A_{lat}
d_2 = the distance from the side of the vehicle at ground level to the far lateral, near longitudinal corner of the lateral vision footprint A_{lat}
d_3 = the distance from the side of the vehicle at ground level to the near lateral, near longitudinal corner of the lateral vision footprint A_{lat}
d_4 = the depth of the lateral vision footprint A_{lat} as measured from the point at which the ground to the front of the vehicle comes into view
d_5 = the distance from the front of the vehicle at which the ground to either side of the hood comes into view

Table A-3

Calculations of Ground Vision and Vehicle Reference Provided by Camera Positions 1 through 10

	CAMERA POSITION									
	1	2	3	4	5	6	7	8	9	10
a	1.95	3.76	3.15	2.55	1.95	2.55	3.15	3.76	3.76	3.15
b	0.8	1.1.	1.1	1.1	1.1	1.4	1.4	1.4	1.73	1.73
θ_{cam}	10°	0°	5°	10°	20°	10°	15°	10°	10°	15°
Measure										
d	2.68	3.76	3.15	2.55	1.95	2.00	2.48	2.95	2.39	2.00
d_1	0	3.08	2.47	1.89	0	1.70	2.20	2.73	2.52	2.06
d_2	0	2.12	1.57	1.19	0	1.49	1.19	1.49	1.82	1.48
d_3	0	1.00	1.00	1.00	0	0.79	0.79	0.79	0.64	0.64
d_4	0	1.94	1.88	1.52	0	0.48	2.25	2.64	1.54	1.33
d_5	0	1.82	1.27	1.03	0	1.52	0.23	0.31	0.85	0.68
d_6	0.10	1.04	0.74	0.45	0.17	0.51	0.45	1.09	1.15	0.87
A_{lat}	0	3.10	1.92	0.82	0	0.39	2.04	3.48	2.36	1.50
a'	0.64	0.97	0.94	0.67	0.71	0.27	1.26	1.48	0.94	0.81

a = camera location along the y axis (longitudinal) as measured from the front edge of the vehicle's hood to the point above which the camera body and lens intersect
b = camera height as measured from the front edge of the vehicle's hood to the intersection of the camera body and lens

θ_{cam} = the angle of depression of the camera below the horizontal
d = the distance from the front of the vehicle at which the ground first comes into view
d_1 = the distance from the side of the vehicle at ground level to the far lateral, forward longitudinal corner of the lateral vision footprint A_{lat}.
d_2 = the distance from the side of the vehicle at ground level to the far lateral, near longitudinal corner of the lateral vision footprint A_{lat}
d_3 = the distance from the side of the vehicle at ground level to the near lateral, near longitudinal corner of the lateral vision footprint A_{lat}
d_4 = the depth of the lateral vision footprint A_{lat}
d_5 = the distance form the front of the vehicle at which the ground to either side of the vehicle's hood comes into view
d_6 = the distance lateral to and at the height of the corners of the vehicle's front fenders
A_{lat} = the area of ground viewed to each side of the vehicle forward of the front bumper up to the line where forward vision intersects the ground to the immediate front of the vehicle
a' = the length of hood captured within the VFOV of the camera

Conclusion

In the latter comparison of Positions 1 through 10, Positions 8 and 9 are shown to provide greater visibility in more sectors of the driving scene. However, the benefits offered by Position 10 could not be clearly distinguished from those offered by Position 7. In some sectors of the scene, Position 7 provided greater visibility than Position 10, and in other sectors of the driving scene, Position 10 provided greater visibility than Position 7. Because of the uncertainty as to the impact that differences in visibility in these sectors might have on remote driving performance, it seemed appropriate that the results of the subjective assessment be sustained.

APPENDIX B

GENERAL FORMULAE FOR CALCULATING CAMERA POSITIONING FOR REMOTE DRIVING

GENERAL FORMULAE FOR CALCULATING CAMERA POSITIONING FOR REMOTE DRIVING

INTRODUCTION

During a series of studies conducted on the high mobility multipurpose wheeled vehicle (HMMWV), the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) examined the effects of changes in camera angle and location on driver opinion about the adequacy of the view and the ease of following the path and performing obstacle avoidance tasks. Driver performance of these tasks was also measured for the three camera positions that achieved the best subjective scores. The results of these studies suggested that operator vision needs in those sectors of the scene assessed could be quantified and that camera positions that satisfied these needs could be mathematically determined.

The equations that are presented next and those vision criteria used in their solution were derived to demonstrate this approach. They focus primarily on those sectors of the remote driver's scene examined in the previous subjective assessments. These sectors, as well as the associated visual constraints can, however, be changed, augmented, or expanded, and other equations can be developed to identify camera positioning options that might offer the greatest potential for success in maximizing operator performance. The formulae presented here can be adapted to any size vehicle or camera lens assembly and, when used in conjunction with other engineering criteria, may offer a useful tool in designing a system that best satisfies the needs of both the soldier and the machine.

FORMULAE DESCRIPTION

Vision Criteria

It was assumed that the driving scene could be divided into four fundamental sectors: sky, far and near ground, and the lateral and longitudinal views of the vehicle platform. It was also assumed that for each of these sectors the quantity of vision needed to perform the remote driving task effectively could be described as follows:

• Sky: "Upward visibility should extend to at least 260 mrad (15°) above the horizontal" (MIL-STD-1472D, para. 5.12.5.3). For the camera lens system specified, this is effected at a depression angle of approximately 7° that produces a 35:65 ratio of sky to ground. However, for the purpose of demonstrating this approach, an acceptable ratio is described by a range of values.

This range is defined as no less than 15:85 and no greater than 50:50, which are achieved at camera depression angles of 15° and 0°, respectively.

• Vehicle Reference (lateral and longitudinal views): Some portion of the vehicle's hood, as measured along the longitudinal axis of the vehicle, should be within the remote operator's vertical FOV (VFOV). This view should not extend behind the edge of the vehicle's dashboard so as to avoid potential distraction caused by moving components on board the remote platform. Therefore, for the HMMWV, the length of hood visible to the operator should be no less than 0.3 m (1 ft) but no greater than 1.5 m (5 ft). Also, as a minimum, both corners of the vehicle's front fenders should be visible to the remote operator. This lateral dimension, as measured on the HMMWV, is 2.0 m (6.6 ft).

• Ground: "Trucks should be designed to enable the operator, in the normal operating position, to view the ground at all distances beyond 3.0 m (10 ft) in front of the vehicle" (MIL-STD-1472D, para. 5.12.5.3).

Equations

Given the stated vision criteria, the horizontal (55°) and vertical (43°) FOVs of the selected camera and lens system, the width of the HMMWV's hood (2.0 m) and its height (1.1 m) as measured at the front of the vehicle, some basic trigonometric functions were applied and equations developed to identify camera locations on board the HMMWV that would meet these constraints.

• Sky

For the purpose of illustration, the HMMWV is approximated as a rectangular box with no frontal slope. The vehicle, depicted in Figure B-1, mounts a 1/2-inch CCD camera. The focal length of the camera's lens is 6 mm. For this camera, the 6-mm lens provides a VFOV of approximately 43° and a horizontal field of view (HFOV) of 55°. The minimum 15% sky is achieved at a camera depression angle of approximately 15° (15:85 ratio of sky to ground) below the horizontal.[1] For ground systems, in a situation approximating a flat plane with no obstructions to the horizon, the maximum of 50% sky occurs at a camera depression angle of 0°. This constrains the angle Θ defined in Figure B-1 to the range of 75° to 90° for camera angles between 15° and 0° below the horizontal, respectively.

[1]CCD camera, 1/2-inch frame size, with 6-mm fixed focal length lens, providing 55° horizontal and 43° vertical FOVs.

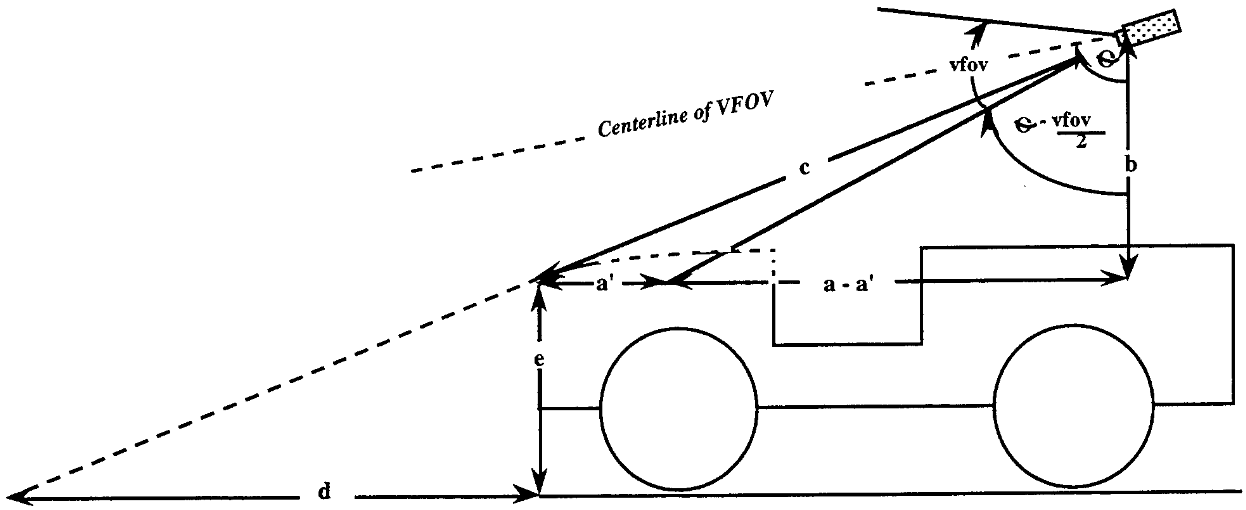

Figure B-1. Defining the constraints of the angle Θ .

in which

$\Theta = 90° - \Theta_{cam}$, in which Θ_{cam} is the camera depression angle from the horizontal
a = camera location along the y-axis (longitudinal) as measured from the front edge of the vehicle's hood
a' = the length of hood captured within the VFOV of the camera
b = camera location along the z-axis (vertical) above the height of the vehicle's hood
c = line of sight to front edge of vehicle
d = distance from the front of the vehicle at which the ground comes within view
e = height of the vehicle's hood

• Vehicle Reference (longitudinal)

The location of the camera along the longitudinal centerline of the vehicle (a) may be calculated for various camera heights (b) to ensure the desired length of vehicle hood (a') in the remote operator's visual field. The formula used to determine the minimum and maximum values of "a" that satisfy the desired constraints can be defined as

$$\mathbf{a} = \mathbf{b} \tan\left(\Theta - \frac{\mathbf{VFOV}}{2}\right) + \mathbf{a'} \qquad \textbf{[1]}$$

in which $\Theta = 90° - \Theta_{cam}$.

Example: For a camera angle of 15° with a VFOV of 43°, in which the camera's elevation (b) is 1.14 m (3.74 ft) above the front edge of the vehicle's hood, if the minimum view of hood is desired (0.3 m), "a_{min}" is calculated as follows:

$$a_{min} = 1.14 \tan(75° - 21.5°) + 0.3 \text{ m}$$

$$a_{min} = 1.84 \text{ m}$$

For a camera angle of 0° with a VFOV of 43°, in which the camera's elevation (b) is 1.45 m (4.76 ft) above the front edge of the vehicle's hood, if the maximum view of hood is desired (1.5 m), "a_{max}" is calculated as follows:

$$a_{max} = 1.45 \tan (90° - 21.5°) + 1.5$$

$$a_{max} = 5.18 \text{ m}$$

• Vehicle Reference (lateral)

The view of the corners of the vehicle's front fenders and the viewing distance lateral to and at the height of these corners, as depicted in Figure B-2, may be calculated with the following equations.

$$\mathbf{W = 2\left(\sqrt{a^2 + b^2}\right)\left(\tan \frac{[HFOV]}{2}\right)} \quad \textbf{[2]}$$

$$\mathbf{w' = \frac{W - W_v}{2}} \quad \textbf{[3]}$$

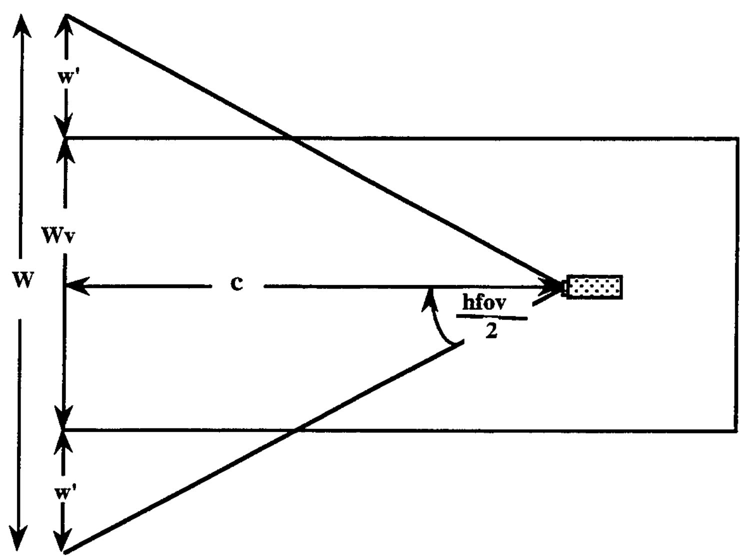

Figure B-2. Vision lateral to and at the height of the vehicle's front fenders.

in which

Wv = the width of the vehicle
w' = the lateral viewing distance beyond each corner of the vehicle's front fenders at the height of the front of the vehicle
hfov = the camera's horizontal FOV

Example: The "a_{min}" calculated above and its corresponding value of "b" are representative examples of "a" and "b", and are used to solve the first equation for "W".

$$\mathbf{W = 2\left(\sqrt{[1.84]^2 + [1.14]^2}\right)(\tan[27.5°])}$$

$$\mathbf{W = (4.3291)\ (.5206)}$$

$$\mathbf{W = 2.25\ m}$$

Solution of the second equation [3] indicates that .13 m lateral vision is provided at the height of and beyond each corner of the HMMWV's front fenders. (Note that $W_v = 2.0$ m.)

$$\mathbf{w' = \frac{2.25 - 2.0}{2}}$$

$$\mathbf{w' = .13\ m}$$

• <u>Ground (Front)</u>

Generally, a maximum or rearmost position of the camera along "a" can be calculated for various camera heights (b) based on the desired ground view close to the front of the vehicle (d) and the height of the hood of the vehicle (e).

$$\mathbf{a \leq \frac{bd}{e}} \qquad \textbf{[4]}$$

Example: As before, the front of the HMMWV is assumed to be square (no frontal slope) and at a height of 1.1 m (3.6 feet) above the ground (e). Again, various camera elevations "b" above this point may be input to this formula, as well as the distance from the front of the vehicle at which the ground should be visible to the remote operator (d). For this example, a ground view 3 m from the front of the vehicle has been specified with a camera height (b) of 1.14 m.

$$\mathbf{a \leq \frac{(1.14)(3)}{1.1}}$$

$$\mathbf{a \leq 3.11\ m}$$

• <u>Ground (sides)</u>

The area of ground view lateral to one side of the HMMWV's hood (A_{lat}) as shown in Figure B-3 is given by Equation [5]:

$$A_{lat} = \frac{1}{2}\frac{(b+e)^2}{b} \quad a'\left(\left[\left[\left\{\sqrt{1+\left(\frac{a}{b}\right)^2} + \sec\left(90° - \left[{}_{cam} + \frac{VFOV}{2}\right]\right)\right\}\tan\left(\frac{HFOV}{2}\right)\right] - \frac{W_v}{b}\right]\right) \qquad [5]$$

in which

$$a' = a - b\tan\left(90° - [\Theta_{cam} + \frac{VFOV}{2}]\right) \qquad [6]$$

and

$$A_{lat\ total} = 2 \times A_{lat} \qquad [7]$$

Several constraints relate to the vision footprint and its dimensions shown in Figure B-3 and to the equation for computing the area of ground view lateral to the sides of the HMMWV. These constraints include those just described for visibility above the horizontal, the lateral and longitudinal views of the vehicle's hood and fenders, and ground vision to the immediate front of the vehicle, along with two additional constraints.

The first of these latter two constraints enables the remote driver to see beyond the left and right edges of the vehicle's hood and thus have a lateral vision footprint (A_{lat}). If this constraint is not met, $A_{lat} = 0$.

$$b\sec\left(90° - [\Theta_{cam} + \frac{VFOV}{2}]\right)\tan\frac{HFOV}{2} \geq \frac{W_v}{2} \qquad [8]$$

The second determines whether the y value of the beginning of the lateral vision footprint (A_{lat}) falls in front of or to the rear of the vehicle's front bumper.

$$(b+e)\tan\left(90° - [\Theta_{cam} + \frac{VFOV}{2}]\right) > a \qquad [9]$$

$$(b+e)\tan\left(90° - [\Theta_{cam} + \frac{VFOV}{2}]\right) \leq a \qquad [10]$$

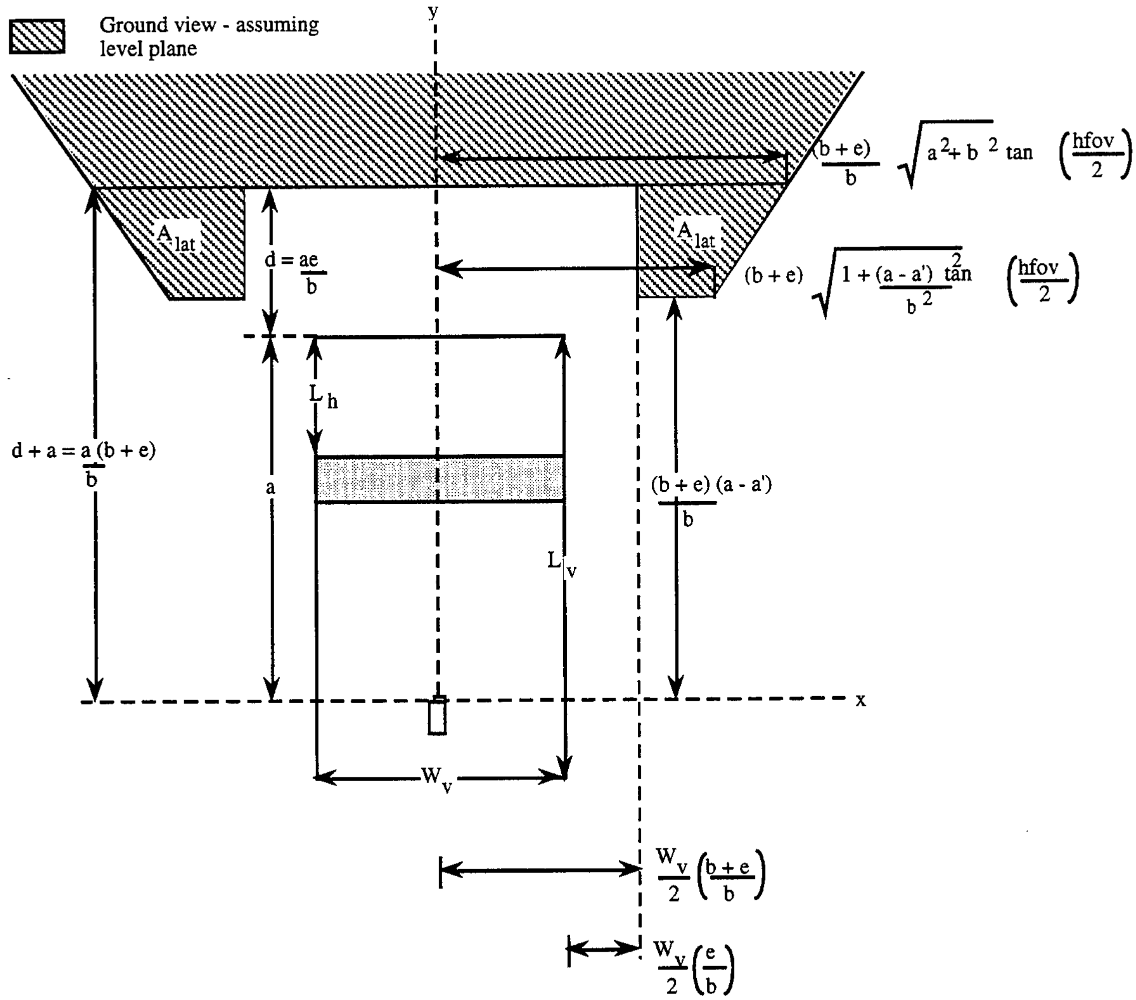

Figure B-3. Equations to define the dimensions of the ground view lateral to the sides of the HMMWV.

in which

a = camera location along the y-axis (longitudinal) as measured from the front edge of the vehicle's hood
a' = the length of hood captured within the VFOV of the camera
b = camera location along the z-axis (vertical) above the front edge of the vehicle's hood
e = the height of the front of the vehicle's hood
$\boldsymbol{\Theta_{cam}}$ = the angle of depression of the camera below the horizontal
vfov = the vertical FOV of the camera
hfov = the horizontal FOV of the camera
Wv = the width of the vehicle
$\mathbf{L_v}$ = the length of the vehicle
$\mathbf{L_h}$ = the length of the hood of the vehicle

By meeting Equation [9] by a given choice of "a," "b," and "Θ_{cam}," one can force the y value of the beginning of the lateral vision footprint (A_{lat}) to fall in front of the front bumper as shown in Figure B-3, and as it did for those camera positions addressed in this study and in the previous subjective assessments.

By meeting the second equation by a given choice of "a," "b," and "Θ_{cam}," one can force the y value of the beginning of the lateral vision footprint to fall to the rear of the front bumper.

Solution

Figure B-4 depicts the camera[1] positioning zones on board the HMMWV that were calculated using Equations [1] through [4] and the original set of vision constraints. The lighter shaded area defines the region on the HMMWV wherein the camera that satisfies a minimum 15% view above the horizontal, or an approximate 15:85 ratio of sky to ground (15° camera depression angle), must be located to meet the additional constraints of ground view ($\leq$ 3 m) and vehicle reference ($\geq$ .3 m and $\leq$ 1.5 m). If a 50:50 sky to ground ratio is desired, a depression angle of 0° is required. The diagonal lines define the positioning zone for a camera with a depression angle of 10° that would yield an approximate 28:72 ratio of sky to ground. The darker shaded area represents the positioning zone for a camera angle of 0°. As can be seen, this set of vision criteria severely limits camera-positioning options for this latter angle of depression.

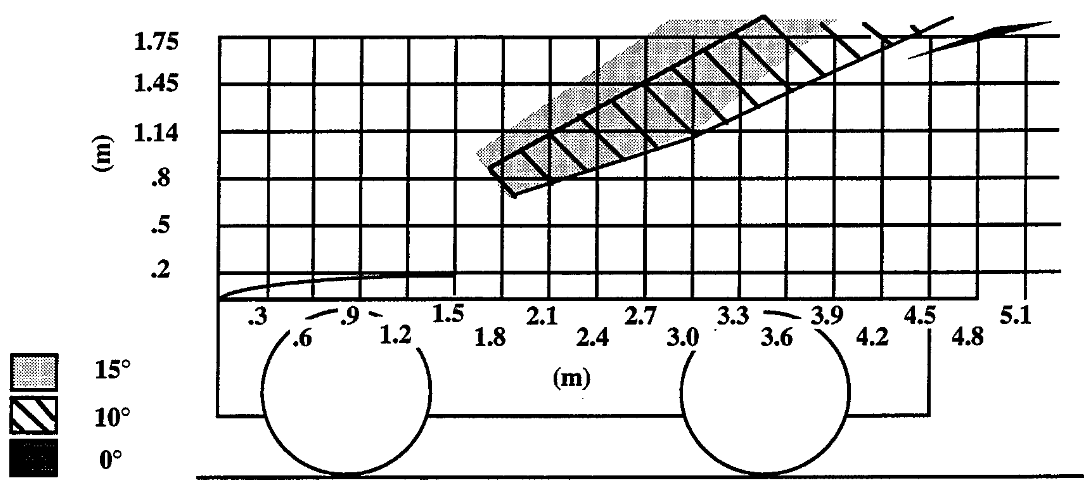

Figure B-4. Camera-positioning zones on the HMMWV to achieve a 15:85 to 50:50 ratio of sky to ground, ground view $\leq$ 3 m to the front of the vehicle, and a 0.3-m to 1.5-m longitudinal and $\geq$ 2.0-m lateral view of the vehicle's hood.

Figure B-5 shows camera-positioning zones that were recomputed to reflect an additional requirement that the ground to either side of the vehicle's hood be visible at or within 1.0 m from the front of the vehicle. As can be seen, the area within which a camera may be mounted to meet this and the previous set of constraints has been reduced, particularly for camera angles of 10°.

[1] CCD camera, 1/2-inch frame size, with 6-mm fixed focal length lens, providing 55° horizontal and 43° vertical FOVs.

There are no longer any positioning options for cameras at depression angles of 0°. As shown in Figure B-6, only Positions 8 and 9 and Positions 7 and 10 remain within the zones of acceptability for their respective angles of depression of 10° and 15°. Figure B-7 shows zones of acceptability that were recomputed for camera angles of 10° and 15° using a more stringent requirement that the ground to either side of the vehicle's hood be visible at or within 0.5 m from the front of the vehicle. As can be seen, only camera Positions 7 and 8 remain within the zones of acceptability for their respective depression angles of 15° and 10°.

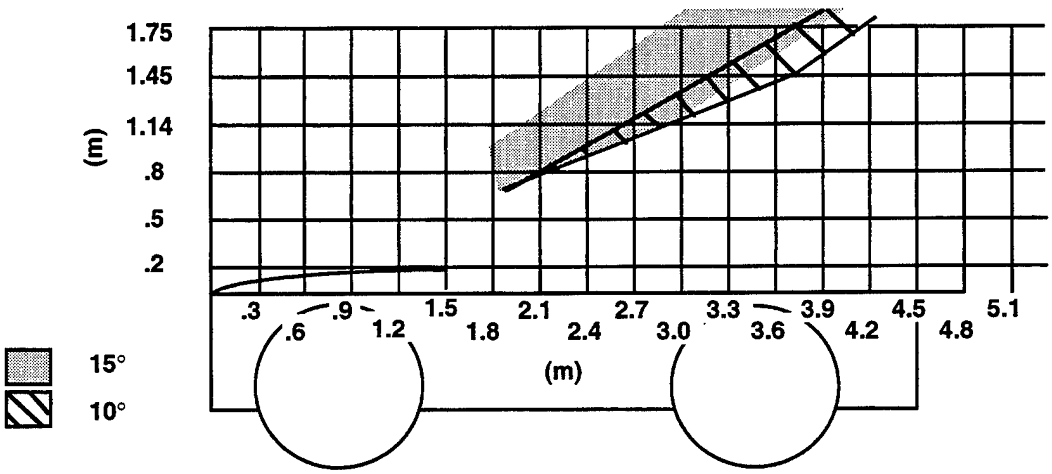

Figure B-5. Camera-positioning zones on the HMMWV to satisfy an additional requirement that the ground to either side of the vehicle's hood be visible at or within 1.0 m from the front of the vehicle.

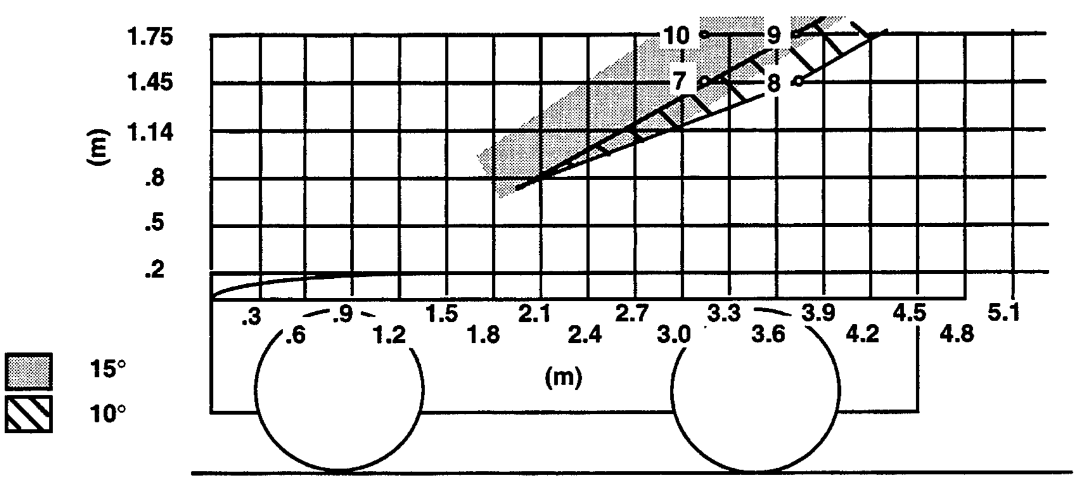

Figure B-6. Camera positions in earlier subjective assessment that satisfy an additional requirement that the ground to either side of the hood be visible ≤1.0 m from the front of the vehicle.

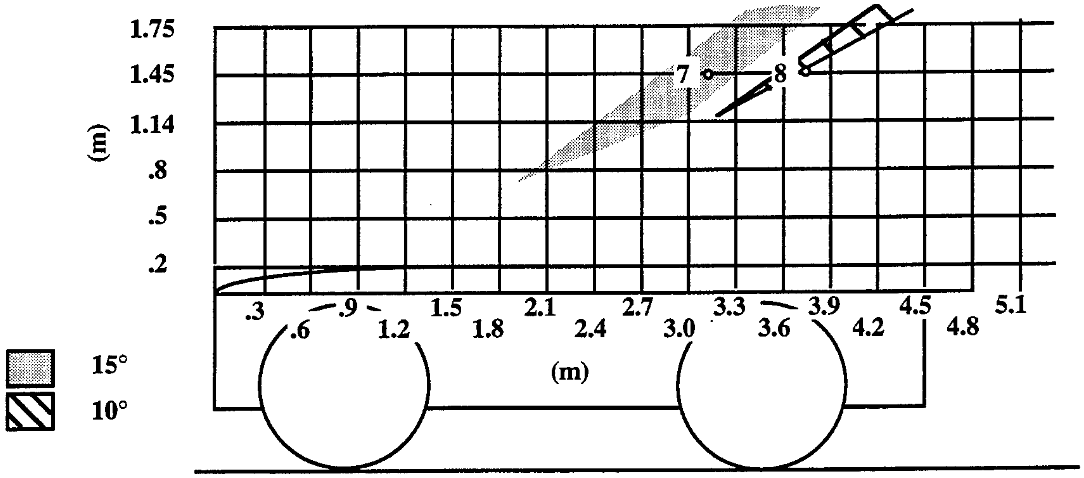

Figure B-7. Camera positions in earlier subjective assessment that satisfy an additional and more stringent requirement that the ground to either side of the hood be visible $\leq$0.5 m from the front of the vehicle.

APPLICATION

A computer program has also been written to calculate the optimal camera position (i.e., a, b, Θ_{cam}) for any given height of the vehicle's hood (e), vehicle width (W_V), vehicle length (L_V), and the HFOV and VFOV of the camera lens system. The program can be used to compute optimal camera position (i.e., height, distance from the front of the vehicle, and camera angle), based upon one or a combination of visual characteristics judged to be most important to the performance of a task. For example, while still meeting all of the visual constraints just defined, one can determine the camera position that yields the largest area of ground view to the sides of the vehicle with the smallest resultant intercept distance of the ground to either side of the vehicle's hood. The program is currently generic for any vehicle dimensions with the assumption that the vehicle has the general geometric shape of a rectangular box.

Use of the equations just presented or the computer program to determine camera-positioning options requires assumptions about those sectors of the scene important to the performance of the task as well as the quantity of vision needed in each of these sectors to perform the task effectively. Similar equations can be developed for any size vehicle and hood

contour, lens focal length, and size of CCD imager[2], but critical parameters of the remote operator's view must first be defined when trying to apply the formulae to other remotely operated systems and tasks. These parameters may be expressed in terms of a range of acceptability or a more specific quantity or proportion. As demonstrated previously, as more stringent constraints are imposed on the remote operator's view in one or more sectors of the scene, or the range of what is considered to be an acceptable view narrowed, the size of the camera-positioning zones depicted will decrease along with the number of camera-positioning options.

[2]The following formula may be used to calculate the sky-to-ground ratios at various camera angles, based on the size of CCD imager and the focal length of the camera's lens:

$$\text{Ground} = \frac{\tan(\text{angle}) \cdot \text{focal length} \cdot 100\%}{\text{frame size of CCD imager}} + 50\%$$

$$\text{Sky} = \frac{\tan(\text{angle}) \cdot \text{focal length} \cdot 100\%}{\text{frame size of CCD imager}} - 50\%$$

APPENDIX C

PRE-TEST QUESTIONNAIRE

PRE-TEST QUESTIONNAIRE

Please answer the following questions. The information you provide will be kept <u>*CONFIDENTIAL.*</u>

1. Name: ____
   Last First Middle Initial

2. If you are **military**, please provide the following information:

   Rank: _________________

   Military Occupational Specialty (MOS): _______________

   Time in Service: ______years

3. If you are **civilian**, what is your job title? ________________

4. Age: __________

5. Height: __________

6. Weight: __________

7. Are you left- or right-handed?

   Left-Handed [ ] Right-Handed [ ]

8. Do you wear eyeglasses or contacts?

   Yes [ ] No [ ]

9. Do you have a civilian drivers license?

   Yes [ ] No [ ]

   If YES, how many years have you been licensed to drive?

   _______years

10. Do you have a military driver's license?

    Yes [ ] No [ ]

If YES, what military vehicles are you qualified to drive?

Vehicle Type	How many years?
____________________	________ years
____________________	________ years
____________________	________ years
____________________	________ years

11. Have you ever done any high performance competitive driving (for example, drag racing, stock car racing, autocross, etc.)?

Yes [ ] No [ ]

If YES, describe

____

____

____

12. How often do you play video or arcade games? *(Check one)*

All the Time [ ]
Often [ ]
Sometimes [ ]
Rarely [ ]
Never [ ]

13. Have you ever operated a vehicle remotely (toy or otherwise)?

Yes [ ] No [ ]

If YES, describe

____

____

____

14. Have you ever been motion sick (for example: seasick, carsick, airsick, trainsick, etc.) ?

Yes [ ] No [ ]

If YES, describe

____

____

____

15. How susceptible are you to motion sickness? *(Check one)*

Extremely	[ ]
Very	[ ]
Moderately	[ ]
Minimally	[ ]
Not at All	[ ]

APPENDIX D

CAMERA POSITIONING QUESTIONNAIRE

1

CAMERA POSITION

For each course segment, please answer the questions below by putting an "X" in the appropriate box at the right.

Straightaway

		Extremely	Moderately	Slightly	Neutral	Slightly	Moderately	Extremely	
How easy or difficult was it to perform this driving maneuver with the camera in this position?	**Easy**	☐	☐	☐	☐	☐	☐	☐	**Difficult**
How much more or less of each of the following do you think you need to see to perform this maneuver?									
Sky?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Ground close-in to front of vehicle?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Vehicle hood?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Edges of front fenders?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Other? (Please specify:__________)	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**

Serpentine

		Extremely	Moderately	Slightly	Neutral	Slightly	Moderately	Extremely	
How easy or difficult was it to perform this driving maneuver with the camera in this position?	**Easy**	☐	☐	☐	☐	☐	☐	☐	**Difficult**
How much more or less of each of the following do you think you need to see to perform this maneuver?									
Sky?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Ground close-in to front of vehicle?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Vehicle hood?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Edges of front fenders?	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**
Other? (Please specify:__________)	**Less**	☐	☐	☐	☐	☐	☐	☐	**More**

(2)

CAMERA POSITIONING QUESTIONNAIRE

Moderately Extremely

☐	☐	Difficult
☐	☐	More
☐	☐	More
☐	☐	More
☐	☐	More
☐	☐	More
☐	☐	Difficult
☐	☐	More
☐	☐	More
☐	☐	More
☐	☐	More
☐	☐	More

CAMERA POSITION *(CONTINUED)*

Slalom

		Extremely	Moderately	Slightly	Neutral	Slightly	Moderately	Extremely	
How easy or difficult was it to perform this driving maneuver with the camera in this position?	**Easy**	☐	☐	☐	■	☐	☐	☐	**Difficu**
How much more or less of each of the following do you think you need to see to perform this maneuver?									
Sky?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Ground close-in to front of vehicle?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Vehicle hood?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Edges of front fenders?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Other? (Please specify:__________)	**Less**	☐	☐	☐	■	☐	☐	☐	**More**

Parking

		Extremely	Moderately	Slightly	Neutral	Slightly	Moderately	Extremely	
How easy or difficult was it to perform this driving maneuver with the camera in this position?	**Easy**	☐	☐	☐	■	☐	☐	☐	**Difficu**
How much more or less of each of the following do you think you need to see to perform this maneuver?									
Sky?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Ground close-in to front of vehicle?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Vehicle hood?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Edges of front fenders?	**Less**	☐	☐	☐	■	☐	☐	☐	**More**
Other? (Please specify:__________)	**Less**	☐	☐	☐	■	☐	☐	☐	**More**

3

(CONTINUED)

	Extremely	Moderately	Slightly	Neutral	Slightly	Moderately	Extremely	
Easy	☐	☐	☐	■	☐	☐	☐	**Difficult**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**

Easy	☐	☐	☐	■	☐	☐	☐	**Difficult**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**
Less	☐	☐	☐	■	☐	☐	☐	**More**

APPENDIX E

MOTION SICKNESS QUESTIONNAIRE

1

Name:	
Training Run #:	
Testing Run #:	

Motion Sickness Questionnaire

INSTRUCTIONS: For each item listed, place an " **X**" in the box to correspond to **HOW YOU FEEL AT THIS MOMENT.** PLEASE ANSWER EVERY ITEM.

	Not at All	Slight	Somewhat	Moderate	Quite a Bit	Extreme
1 Generally uncomfortable	☐	☐	☐	☐	☐	☐
2 Tired	☐	☐	☐	☐	☐	☐
3 Depressed	☐	☐	☐	☐	☐	☐
4 Sleepy	☐	☐	☐	☐	☐	☐
5 Headache	☐	☐	☐	☐	☐	☐
6 Dizzy (with eyes closed)	☐	☐	☐	☐	☐	☐
7 Dizzy (with eyes open)	☐	☐	☐	☐	☐	☐
8 Disoriented	☐	☐	☐	☐	☐	☐
9 Sweaty	☐	☐	☐	☐	☐	☐
10 Faint	☐	☐	☐	☐	☐	☐
11 Aware of my breathing	☐	☐	☐	☐	☐	☐
12 Nauseous (Sick to stomach)	☐	☐	☐	☐	☐	☐
13 Burping	☐	☐	☐	☐	☐	☐

14 H
15 N
16 C
17 Bl
18 D (d
19 In
20 H
21 C
22 V

(2)

Extreme
☐
☐
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☐
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☐
☐
☐
☐
☐
☐

	Not at All	Slight	Somewhat	Moderate	Quite a Bit	Extreme
14 Hungry	☐	☐	☐	☐	☐	☐
15 No appetite	☐	☐	☐	☐	☐	☐
16 Chills	☐	☐	☐	☐	☐	☐
17 Blurred vision	☐	☐	☐	☐	☐	☐
18 Decreased salivation (dry mouth)	☐	☐	☐	☐	☐	☐
19 Increased salivation	☐	☐	☐	☐	☐	☐
20 Hot flashes	☐	☐	☐	☐	☐	☐
21 Clammy	☐	☐	☐	☐	☐	☐
22 Vomiting		YES ☐		NO ☐		

Thank you

3

Moderate	Quite a Bit	Extreme
☐	☐	☐
☐	☐	☐
☐	☐	☐
☐	☐	☐
☐	☐	☐
☐	☐	☐
☐	☐	☐
☐	☐	☐
NO ☐		

APPENDIX F

SUBJECTIVE ASSESSMENT AND ANALYSIS OF RATINGS OF CAMERA POSITIONS 8, 9, AND 10

SUBJECTIVE ASSESSMENT AND ANALYSIS OF RATINGS OF CAMERA POSITIONS 8, 9, AND 10

Table F-1

Tabulation of Subjects' Ratings of Ease of Performance by Course Segment

Subjective Measure		Course Segment															TOTAL
		Straightaway			Serpentine			Slalom			Parking			Overall			
		8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	
EASE OF PERFORMANCE	Difficult	5	8	6	15	15	11	14	19	17	11	8	4	45	50	38	133
	Neutral	11	8	8	7	9	9	12	7	5	11	13	11	41	37	33	111
	Easy	20	20	22	14	12	16	10	10	14	14	15	21	58	57	73	188
TOTAL		108			108			108			108						432

Table F-2

Tabulation of Subjects' Ratings of Adequacy of the View by Vision Sector and Course Segment

Subjective Measure		Vision Sector															TOTAL
		Sky			Ground			Hood			Fender			Overall			
		8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	
ADEQUACY OF VIEW (Vision Needs)	More	14	7	10	76	61	58	13	13	13	56	63	60	159	144	141	444
	Neutral	89	92	101	53	60	61	88	91	100	69	63	65	299	306	327	932
	Less	41	45	33	15	23	25	43	40	31	19	18	19	118	126	108	352
TOTAL		432			432			432			432						1728

Subjective Measure		Course Segment															TOTAL
		Straightaway			Serpentine			Slalom			Parking			Overall			
		8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	
ADEQUACY OF VIEW (Vision Needs)	More	22	30	24	44	36	42	50	45	42	43	33	33	159	144	141	444
	Neutral	91	81	94	68	73	74	64	67	74	76	85	85	299	306	327	932
	Less	31	33	26	32	35	28	30	32	28	25	26	26	118	126	108	352
TOTAL		432			432			432			432						1728

Table F-3

Ease of Performance by Course Segment

Course segment	Ease of performance			
	Difficult	Neutral	Easy	Total
Straightaway[a]	19	27	62	108
Serpentine[b]	41	25	42	108
Slalom[b]	50	24	34	108
Parking[a]	23	35	50	108
Total	133	111	188	432

[a]Differences between these items are not statistically significant.
[b]Differences between these items are not statistically significant, but differences between these items and those annotated by "a" are significant at <.05.

Table F-4

Adequacy of the View by Sector of the Driving Scene

Sector	Vision needs			
	More	Neutral	Less	Total
Sky[a]	31	282	119	432
Ground (front)[b]	195	174	63	432
Hood[a]	39	279	114	432
Front fenders[b]	179	197	56	432
TOTAL	444	932	352	1728

[a]Differences between these items are not statistically significant.
[b]Differences between these items are not statistically significant, but differences between these items and those annotated by "a" are significant at <.01.

Table F-5

Adequacy of View by Course Segment

Course segment	Vision needs: More	Neutral	Less	Total
Straightaway [b]	76	266	90	432
Serpentine [a]	122	215	95	432
Slalom [a, c]	137	205	90	432
Parking [a, c]	109	246	77	432
Total	444	932	352	1728

[a]Differences between these items are not statistically significant.
[b]Differences between this and items annotated by "a" are significant at <.05.
[c]Differences between these items are significant at <.05.

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13. ABSTRACT *(Maximum 200 words)*

This report describes a study that compares the effects of three camera positions on remote driving performance of a high mobility multi-purpose wheeled vehicle (HMMWV). The three camera positions assessed had been selected during a previous study based on driver opinion about the adequacy of the view and the ease of performing the remote driving task.

The present study was conducted on an outdoor course that consisted of a straightaway, slalom, serpentine, and parking segment. These segments were configured using traffic cones.

No significant differences were found among the three camera positions in course completion time; however, those traffic cones that defined the slalom and serpentine segments of the course were hit significantly less often in one camera position than in the other two. Further analyses revealed relationships between camera height and course completion time and error. Relationships were also found between time and error and the distance from the front of the vehicle at which the ground to either side of the vehicle's hood was visible.

The report includes equations to assist in identifying camera position options that offer the most efficient and effective distribution of the driving scene among sky, far and near ground, and the teleoperated platform.

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